The Importance Of Fisheries Waste

In The Diet Of Westland Petrels (*Procellaria westlandica*)

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Westland petrels *Procellaria westlandica* breed only near Punakaiki on the West Coast of New Zealand. About 80 km offshore from their breeding colony, New Zealand's largest commercial fishery (for hoki *Macruronus novaezelandiae*) operates from mid June to early September, coinciding with the Westland petrel's breeding season.

It has been assumed that Westland petrels feed extensively on fisheries waste and that this habit has been at least partly responsible for the increase in the Westland petrel population. Some seabird biologists have expressed concern that if a species comes to depend on scavenging at fishing vessels, such a species could experience a food crisis if fishing operations changed in a way that reduced the quantity of waste discharged. The aim of this research was to assess how dependent Westland petrels have become on fisheries waste for food.

Diet studies showed that during the hoki fishing season, waste accounts for more than half by weight of the solid food Westland petrels bring back to the colony to feed their chicks. After the hoki season, waste contributes only about a quarter of their diet as birds switch to more natural prey and scavenge a wider variety of fish species presumably from smaller, inshore fishing vessels.

Much of the fisheries waste eaten by Westland petrels was flesh which could not be identified using traditional techniques. The electrophoretic technique iso-electric focusing increased the number of fish samples that could be identified and consequently the diet was interpreted differently than it would have been had only traditional diet analysis been used.

The survey of Westland petrel distribution off the west coast of the South Island, found that although hoki fishing vessels influence the distribution of Westland petrels, only a small proportion of the Westland petrel population appears to utilise this food resource at any one time.

Westland petrels were tracked at sea by VHF radio telemetry and then by satellite tracking. Satellite tracking showed that there is considerable variation in the amount of time Westland petrels spend in the vicinity of fishing vessels. On average, satellite tracked birds spent one third of their time near vessels, but they foraged over much larger areas than that occupied by the West Coast South Island hoki fishing fleet.

Although fisheries waste is an important component of the Westland petrel diet, it appears that the situation is one of opportunistic use of a readily available resource, rather than one of dependence. Several features of the Westland petrel's breeding biology and foraging ecology suggest that Westland petrels could compensate for a reduction in waste from the hoki fishery by switching to other sources of waste and increasing their consumption of natural prey.

Nevertheless, much remains unanswered concerning the role of fisheries waste in the Westland petrel's diet. In particular, quantifying the waste available to seabirds, and the success of Westland petrels in acquiring that waste compared to other scavenging species, is needed in order to better predict the effect of a reduction in fisheries waste on Westland petrel population size.

Keywords: Westland petrel *Procellaria westlandica,* hoki *Macruronus novaezelandiae*, fisheries waste, diet, population, distribution, iso-electric focusing, satellite tracking, Geographical Information System.

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Chapter 1.

Introduction

Westland petrels *Procellaria westlandica* breed only near Punakaiki on the West Coast of New Zealand's South Island. Although their population, now possibly numbering 20 000 birds including breeders and non breeders, is still small, it is believed to have increased significantly since the 1950s. A key factor in this growth is thought to have been increased food in the form of waste from fisheries[1], especially the large scale West Coast fishery for hoki *Macruronus novaezelandiae*. However, there has been almost no previous research on the diet and foraging patterns of Westland petrels. Understanding breeding season diet and foraging patterns, and quantifying the importance of fisheries waste, are essential to predicting the potential impacts of changes in fishing practices on Westland petrel breeding success and population size. This research was designed to assess the extent to which Westland petrels are dependent on fishing operations for food.

Westland Petrels

Westland petrels are one of the largest burrowing seabirds with a wingspan of around 137 cm. Females weigh around 1100 g and males average 1200 g. They breed in winter in colonies under dense coastal rainforest (Fig. 1) between the Punakaiki River and Waiwhero Creek, West Coast, New Zealand. Ninety-five percent of known burrows are protected in the Paparoa National Park and Dick Jackson Memorial Reserve. This research was carried out at the Scotchmans' Creek sub-colony in Paparoa National Park (Figs. 2&3).

[1] Fisheries waste includes all fish and fish parts discharged from fishing vessels.

Figure 1. Part of the Westland petrel study site showing coastal rainforest vegetation. A Westland petrel burrow is marked with a stake and access lid in the middle left of the photograph (photo A.B. Freeman).

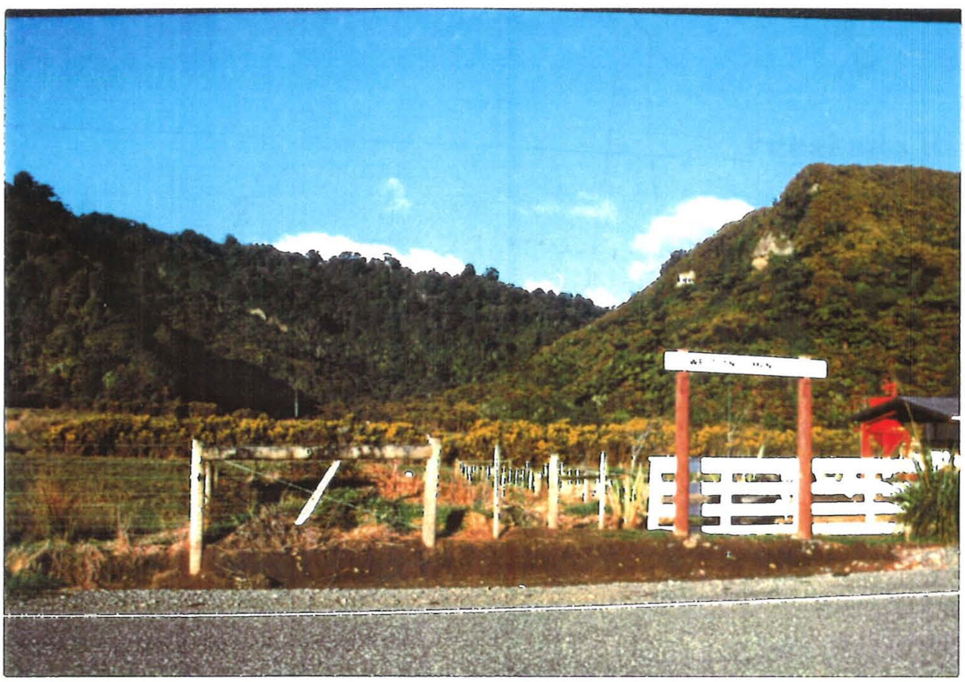

Figure 2. The Westland petrel study site viewed from the main road. Study burrows were located on the ridge in the centre of the photograph (photo A.B. Freeman).

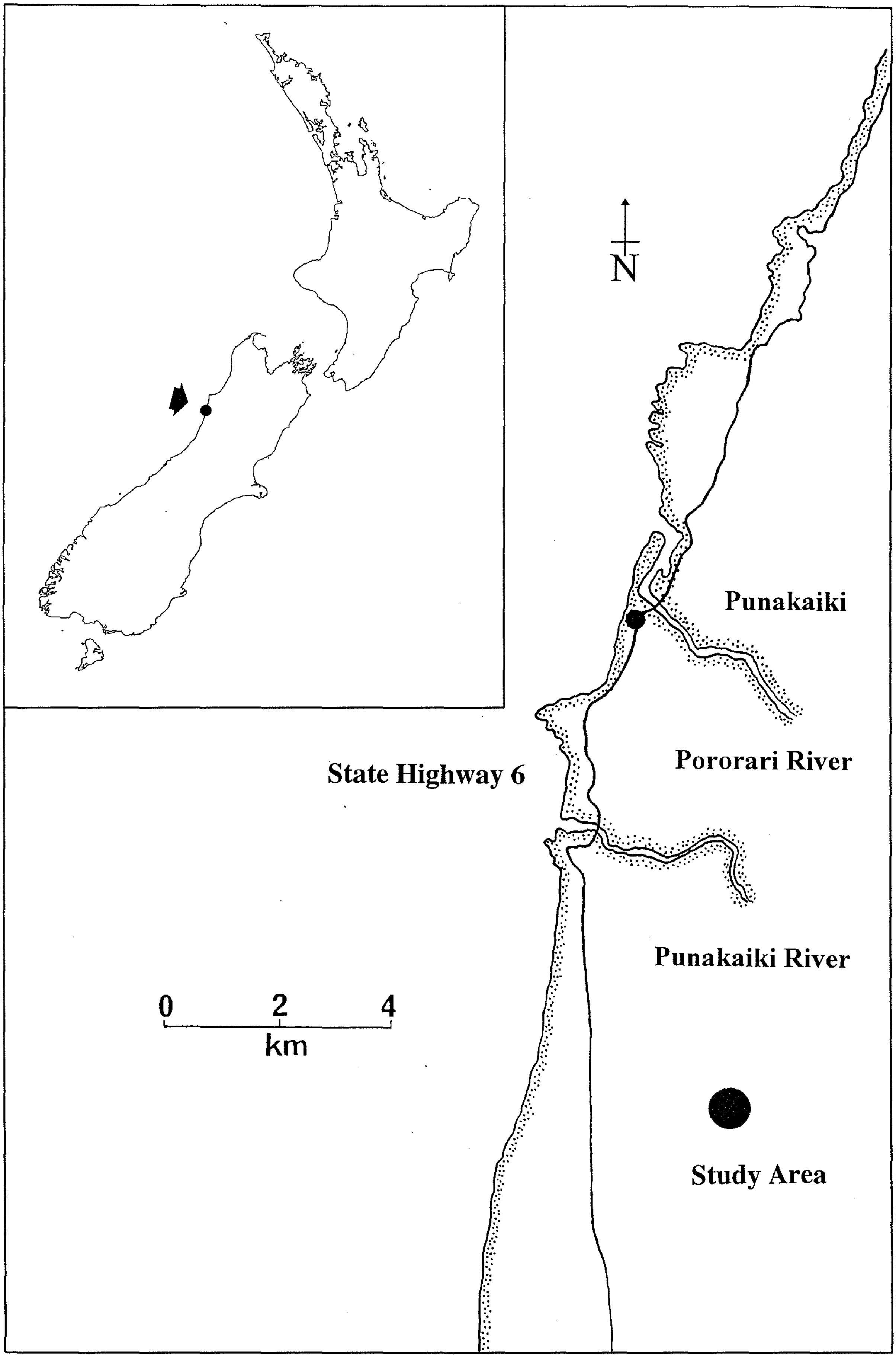

Figure 3. Map showing the location of the Westland petrel study site.

Westland petrels are annual breeders with approximately 84% of successful breeders in any one year returning to breed in the following season (J. A. Bartle; A.N.D. Freeman unpublished data). Egg laying is well synchronised and constant from year to year, beginning about 12 May and peaking around 23 May with a few eggs laid in early June. Hatching occurs mostly in the last half of July and the chick is guarded by one or both parents for about two weeks although this period may range from a few days to six weeks (Marchant & Higgins 1990). This period is unusually long as 2-3 days is the typical length of the guard stage in burrowing Procellariiformes (Warham 1996). Like other *Procellaria*, Westland petrels have a long chick rearing period with fledging taking place between 5 November and 15 January with a peak about 20 November (Marchant & Higgins 1990). Breeding success varies greatly from year to year. From 1976-1991 the mean percentage of eggs laid in study burrows that resulted in fledged chicks was 39% (range 20-63%) (Department of Conservation 1996). Since 1991 however, breeding success has been higher (mean 50%; range 38-63%, pers. obs.).

During the breeding season Westland petrels mostly feed over the continental shelf and upper continental slope. At this time they are found north of the subtropical convergence east and west of New Zealand (Fig. 4) (Marchant & Higgins 1990). Westland petrels are rare in New Zealand waters outside of the breeding season. They migrate to the central and east Pacific Ocean after breeding, possibly as far east as South America (Marchant & Higgins 1990).

Because of the species' past poor breeding success and it's restricted breeding distribution, the Westland petrel is considered "vulnerable" (Department of Conservation 1996). Although the subject of a long term population study since the 1970s, most data on Westland petrel population trends is unpublished, making it difficult to assess the reliability of the population estimates quoted here. However, capture-recapture analysis of banded birds has indicated that the Westland petrel population expanded at an average rate of about 5% per annum between 1953 and 1985 when it peaked at 20 000 $\pm$ 5 000 birds. Since then, population modelling has indicated a decline (Bartle 1987; Department of Conservation 1996). The long period of population growth was thought to have been partly a result of increased food in the form of fisheries waste, and the subsequent decline a result of the reduction in trawling on the West Coast (Bartle 1985 and 1987). Bartle (1987) speculated that the observed lower survivorship of adult females could be due to competition between males and females for food. He considered that numbers of the heavier, more aggressive males could have been inflated by trawling and that the lighter females could be at a disadvantage as trawl waste became less available. Until now there have been no diet studies to test this assertion. More recently, capture of females by tuna longliners has also been implicated in lower female survivorship (Department of Conservation 1996).

Feeding on fisheries waste has also been implicated in the feather malformation present in 20-30% of Westland petrel fledglings (J.A. Bartle unpublished data). Feathers on these chicks are brittle with incompletely formed barbules. Bartle suggested that this condition is due to a nutrient imbalance in the diet given to chicks which may have been fed mostly with fisheries waste (Marchant & Higgins 1990).

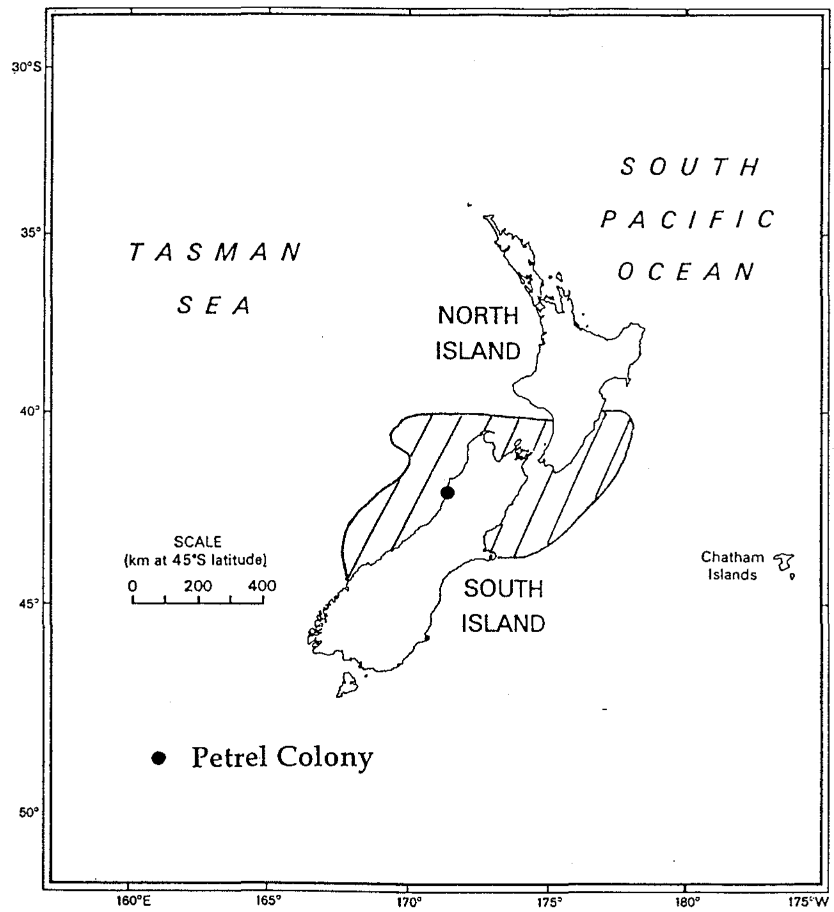

Figure 4. Main distribution of Westland petrels at sea during the breeding season (from Marchant & Higgins 1990 and J.A. Bartle unpublished data).

The Westland petrel was not recognised as a distinct species until 1946 (Falla 1946) so records of this species extend back only 50 years. In the 1950s the Westland petrel population was reliably estimated to be between 3 000 individuals and 3000 pairs on the basis of counts of birds returning to the colonies and estimates of the number and size of sub colonies (Jackson 1958). Jackson (1958) considered that the population may have declined because of the numerous unoccupied burrows. However, many burrows on the Westland petrel colony are unoccupied today, despite the apparent increase in the population, and this is probably due to unsuitable burrows being abandoned (pers. obs.). Bartle (1974) estimated the population at all the colonies in 1972 to be between 6 000 and 10 000 birds, including non-breeders, in contrast to Best & Owen (1976) who thought that there had been no large-scale change in the distribution of breeding areas since Jackson's survey, and counted only 818 occupied burrows over the whole area. Baker & Coleman (1977) found the above estimates hard to reconcile with one another and considered it impossible to tell from the available information whether or not the population was increasing. Bartle's more thorough survey of the area (1969 and on going) showed that Best and Owen had under-counted sub colonies and missed other large sub colonies. The number of occupied burrows in 1974 was estimated by Bartle to be 1 800 in the entire area (J.A. Bartle unpublished data). A more detailed analysis of population trends since that time will be provided by publication of the results of Bartle's long term monitoring work (J. A. Bartle pers. comm.).

Whatever the past population trends or former importance of waste from fisheries may have been, the size and proximity of large scale fisheries to the Westland petrel's breeding colonies means that there is currently the potential for Westland petrels to supplement their diet with fisheries waste and possibly maintain their population at an artificially high level.

Seabird Population Increases and Fisheries

A fundamental assumption underlying any research on the relationship between seabird population increases and scavenging on fisheries waste is that seabird populations, or aspects of their reproductive performance, are limited by prey abundance. Whether or not competition for food is usually of great significance for seabirds has been debated; many seabird species search pelagic seas and are widely dispersed, suggesting that it may be the bird's ability to find food (not the quantity of food itself) that is limiting (Warham 1996). There is, however, good evidence that seabirds are regulated by food availability as suggested by a number of studies that have shown correlations between measures of prey abundance and aspects of seabird reproductive biology (Hunt *et al.* 1990). One line of evidence comes from the many studies, such as twinning of chicks, that show that changes in the ability of parents to supply food to offspring causes changes in growth and/or survival of chicks; another indication is the correlation observed between some changes in population parameters of seabirds and changes in prey stocks (Croxall & Rothery 1991).

Food availability can potentially influence population levels in several ways. First, food availability can affect the breeding condition of adults, including age at first breeding and subsequent decisions to breed, and hence *breeding frequency*. Second, *breeding success* can be affected by the level of food resources during egg formation, incubation and chick rearing. For example, unattended eggs are vulnerable to predation and a nearby food source may enable birds to incubate more consistently and reduce the predation risk. Lastly, the *survivorship* of adults and pre breeders can be affected by food levels outside of the breeding season.

The use of fisheries waste by scavenging seabirds has received increasing attention in recent years and several studies have found waste to be an important component of the diet of certain seabirds which have learnt to exploit this abundant and readily available food source (Fig. 5). For example, an extensive study of discard consumption by seabirds in the North Sea found that eight species of seabirds utilised fishery waste on a large scale, at least during part of the year (Camphuysen *et al.* 1995). Similarly, Thompson (1992) describes a situation in the Falkland Islands where breeding black-browed mollymawks *Diomedea melanophrys* now obtain 10-15% of their food requirements from the *Loligo gahi* squid fishery during the period when that fishery is operating. Jackson (1988) found that trawl offal was the dominant food by mass of the white-chinned petrel *Procellaria aequinoctialis* in the Benguela Current region, South Africa.

Figure 5. Large numbers of seabirds may gather behind fishing vessels as shown in this photograph taken from the NIWA vessel *Tangaroa* on a research trip in the Southern Ocean.

There is some suggestion that *Procellaria* may be "pre adapted" for scavenging behind fishing vessels. Like some other tube-nose species, they have been known to follow whales, presumably to feed on their faeces and vomit of partially digested squid and other prey, to feed on the debris from the cetaceans dismembered prey, or to take advantage of the whales driving deep sea animals into the bird's diving range (Warham 1996). Jackson (1988) argues that the natural tendency of white-chinned petrels to exploit the feeding activity of whales may account for their propensity to scavenge behind boats. Although there have been no reports of Westland petrels utilising whales, Parkinson's petrel *Procellaria parkinsoni*, and the grey petrel *Procellaria cinerea* have also been shown to feed with cetaceans (Pitman & Ballance 1992; Enticott 1986).

Although variation in food availability has regularly been mooted as a cause of population change, it is difficult to demonstrate clear links between seabird population changes and fisheries. The demographic characteristics of Procellariiformes (low reproductive rates and high adult survival rates) coupled with their pelagic habits make it very difficult to study population regulation in this group. By the time significant changes have been detected, the factors underlying those changes must have operated for years (Croxall & Rothery 1991). One of the most well known and best documented cases of population increase in a seabird species is that of the Northern fulmar *Fulmarus glacialis*. Many followed Fisher (1952) in believing that the fulmar's population expansion was due to the increased availability of offal in the North Sea fisheries. Bailey & Hislop (1978) disputed this stating that "despite the apparently heavy reliance that many seabirds have on fishing vessels, it is impossible to find any unequivocal proof that offal discarded by trawlers has been the major factor in the increase of any seabird". Recent work suggests that the fulmar case is in fact rather complex, with different colonies utilising fisheries waste to widely varying degrees (Camphuysen & Garthe 1996; Hamer *et al.* 1996).

Nevertheless, seabird biologists have expressed concern that, if a large enough proportion of a species' population comes to depend on scavenging at fishing vessels, it could experience a food crisis if fishing operations changed (eg Bartle 1974, Abrams 1983). Recent studies in the Mediterranean provide compelling evidence that this can occur. A trawling moratorium was established around the Ebro Delta gull colony in 1991 and, since that time, several studies have recorded a decrease in the reproductive parameters of Audouin's gull *Larus audouinii*, yellow-legged gull *L. cachinnans* and lesser black-backed gull *L. fuscus* (Oro & Ruiz 1996).

The Hoki Fishery

The hoki fishery is the largest of the commercial fisheries operating close to the Westland petrel breeding colony and is likely to be their most used source of fisheries waste (Figs. 6&7). The main West Coast trawl fishery, centred on spawning hoki at depths between about 300m and 600 m, operates from mid June to early September and is New Zealand's largest commercial fishery in terms of total catch (MAF Fisheries Marine Research Annual Report 1992-1993).

Figure 6. Hoki *Macruronus novaezelandiae* New Zealand's largest commercial fishery in terms of total catch.

Figure 7. A large net of hoki being hauled aboard a vessel in the West Coast South Island hoki fishery.

The height of the hoki fishing season corresponds with the Westland petrel's incubation and early chick rearing period (Fig. 8). As breeding season energy requirements are greatest during the chick guarding period, when a parent always stays with the chick (Ricklefs 1983), the hoki fishery may be a valuable food source at this critical stage of the breeding season.

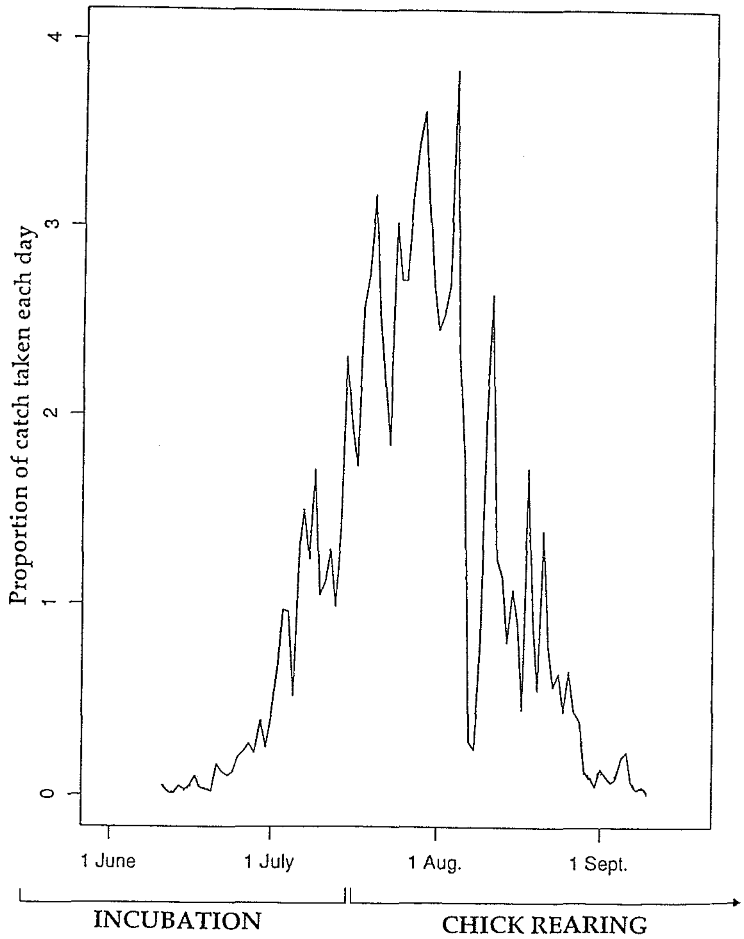

Figure 8. The height of the hoki fishing season corresponds with the Westland petrel's incubation and early chick rearing period as shown in this graph of the daily hoki catch on the West Coast in 1991 (based on Sullivan & Cordue 1992).

The hoki fishery developed in the early 1970s but remained relatively small up to 1985 with annual landings of less than 50 000 t. After 1986 the fishery expanded with estimated landings reaching a maximum of 255 000 t in the 1987/88 fishing year (October-September) and has remained relatively constant at about 210 000 t since then (Horn & Sullivan 1996). Currently, in the main hoki fishing areas, around 100 000 t is caught off the West Coast, and a further 40 000 t in the Cook Strait each year (Fig. 9).

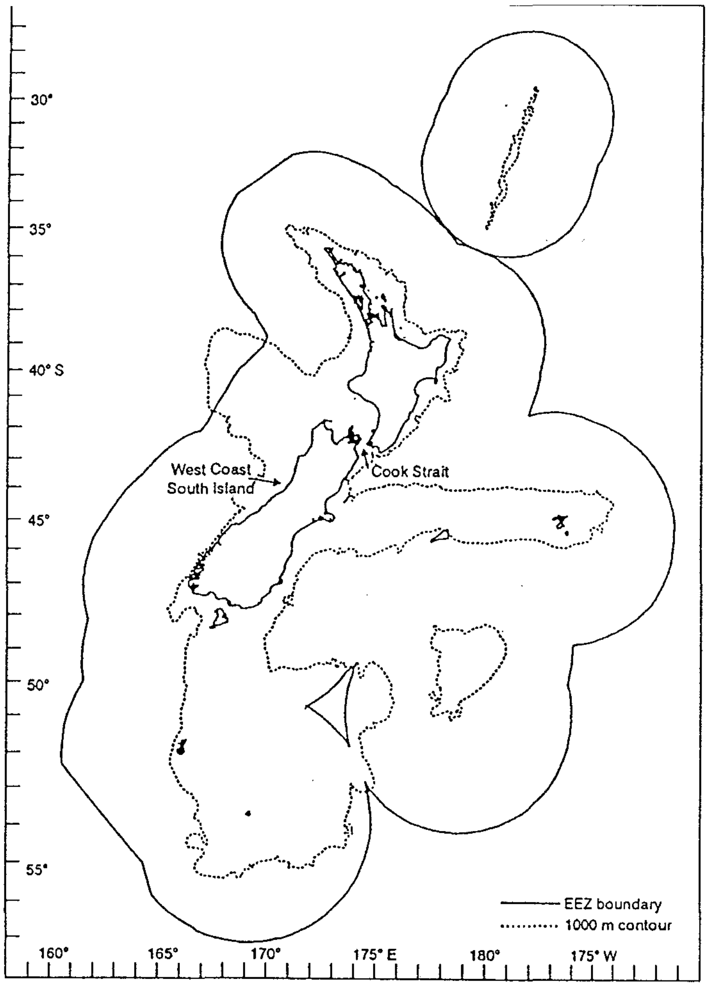

Figure 9. The main hoki fishing areas off the West Coast of the South Island and in Cook Strait (based on Livingston & Schofield 1996).

In recent years the proportion of hoki caught outside of the West Coast area has increased. Hoki is caught in Cook Strait during the winter spawning season, and in other areas during the summer months. The history of catches in the hoki fishery since 1988 is shown in Table 1.

The quantity of waste discharged from the hoki fishery varies depending on the composition and characteristics of the fishing fleets from year to year. For example, Livingston & Rutherford (1988) estimated that 48% of a surimi vessel's[2] catch was dumped as waste compared to 25% of a non-surimi vessel's catch. The proportion of other fish species caught, and hence discarded, in the West Coast hoki fishery is low. For example, in 1991, other commercial species (predominantly hake *Merluccius australis* and ling *Genypterus blacodes*) accounted for no more than 10% of the total catch (Sullivan & Cordue 1992). Small numbers of rattails (Macrouridae) and

[2] A vessel which manufactures fish paste used in seafood and meat flavoured products.

dogfish (Squalidae) are also caught but, being non-quota species, are largely unrecorded (pers. obs.). The waste discharged from the West Coast South Island (WCSI) hoki fishery, therefore, consists mainly of hoki waste with small quantities of other mid-water fish, which would not otherwise be available to seabirds. In the Cook Strait hoki fishery, there are sometimes significant bycatches of ling and spiny dogfish *Squalus acanthius* (Livingston 1990).

Table 1. Estimated total catch (t) of hoki by area (for year October-September).

Year	WCSI	Cook Strait	East Coast & Chatham Rise	Total
1988/89	188 000	7 000	5 000	210 000
1989/90	165 000	14 000	13 000	210 000
1990/91	154 000	26 500	28 500	215 000
1991/92	105 000	25 000	46 000	215 000
1992/93	98 000	21 000	43 000	195 000
1993/94	113 000	37 000	24 000	190 000
1994/95	80 000	40 000	39 000	175 000

(sources: 1988-1990 Sullivan & Cordue 1992; 1991-1993 MAF Fisheries Annual Reports; 1994-1995 S. Ballara pers. comm.)

The volume of waste discharged from the WCSI hoki fishery may have decreased in recent years with the withdrawal of surimi vessels in favour of filleting vessels which produce less waste. In 1991, for example, the surimi component of the WCSI catch was only 39% of the total compared with 60% from 1986 to 1990 (Sullivan & Cordue 1992). Using Livingston & Rutherford's (1988) estimates of the proportion of catch discharged as waste, Sullivan & Cordue's (1992) 1991 ratio of surimi to non surimi catch in the WCSI fishery, and the 1994-95 total catch figure of 175 000 t, I have calculated that the total volume of waste discharged from the hoki fishery is still in the region of 47 000 t per annum. The waste discharged consists of heads, frames (skeleton and flesh remaining after filleting), tails and guts from processed fish and whole discarded fish such as rattails and dogfish. This waste thus forms a very large potential food source for seabirds.

Westland Petrels and Ship Following

In the late 1950s few Westland petrels fed on trawl waste from fishing boats, but the number feeding on the Cook Strait trawling grounds greatly increased during the 1960s (Bartle 1974). In October/November 1975, large numbers of Westland petrels were observed feeding on fisheries waste during exploratory fishing off Greymouth, West Coast (Vooren 1977). In recent years Westland petrels have regularly been observed scavenging behind WCSI hoki trawlers and other fishing vessels (P. Langlands pers. comm.; pers. obs.) but the number of birds seen has seldom been accurately recorded. Where Westland petrels have been counted, the number behind a single vessel at any one time varied from one or two individuals to about 150 (P. Langlands pers. comm.; pers. obs.). Although most observations of scavenging are from the WCSI hoki fishery, other fisheries within the Westland petrel's foraging range, such as the Cook Strait hoki fishery, and the small, inshore set net, trawl and long line fisheries are also potential food sources. Among these are vessels targeting red cod *Pseudophycis bachus,* barracouta *Thyrsites atun,* and gurnard *Chelidonichthys kuma* which are caught in comparatively small quantities (a few hundred to a few thousand tonnes) off the West Coast of the South Island (Annala & Sullivan 1996).

Research Objectives and Approach

The major objectives of this study were:

(1) to determine the importance of fisheries waste in the diet of Westland petrels during the chick rearing period,

(2) to determine whether foraging patterns of Westland petrels are influenced by commercial fishing activity, particularly the WCSI hoki fishery,

(3) to predict how changes in fishing practices may affect Westland petrel breeding success and, ultimately, population size.

Ecological research can be conducted by experimental manipulation of variables and control of confounding effects or, alternatively, by direct observation and description. The former approach is more likely to yield unambiguous results while the latter typically produces results which are at best inferential. The latter approach characterises the vast majority of ecological studies of Southern Ocean seabirds because it is often logistically, economically, or ethically impossible to conduct experimental manipulations and control external variables when working with these species. This study was no exception and was, by necessity, limited by the inability to manipulate the commercial hoki fishing fleet or apply more intrusive methods in the study of the vulnerable Westland petrel. Because of the size of the WCSI hoki fishery, and its proximity to the Westland petrel's breeding grounds, research focussed on this particular fishery. Three different approaches; diet studies, a survey at sea and satellite tracking were used in an attempt to establish how important fisheries waste is in the diet of Westland petrels.

Chapter 2 outlines the general methods used in this study, explains the constraints of weather and terrain that this study operated under and describes some methods which were tested but proved unsatisfactory. Subsequent chapters describe the methodology relevant to each chapter.

Established methods (regurgitation and water offloading) were used to sample the diet of Westland petrels at their breeding colony. Analysis of these samples by the traditional means of identifying hard parts allowed some fisheries waste to be identified and improved knowledge of the range of prey occurring in the Westland petrel's natural diet. This work is reported in a paper prepared for submission to *Emu* which forms Chapter 3 of this thesis.

Early in the diet sampling it became apparent that as a great deal of fisheries waste does not contain any identifiable hard parts, and hence cannot be analysed by conventional means, an additional technique was needed to identify fisheries waste. An electrophoretic technique called iso-electric focusing was used to identify fish species from pieces of flesh found in diet samples. The results of testing this technique are presented in Chapter 4 which has been prepared as a paper for submission to *Comparative Biochemistry and Physiology*.

A complementary approach to the land-based diet studies was a survey of Westland petrels at sea off the West Coast of the South Island. This enabled the relationship between the Westland petrel's distribution at sea and the positions of fishing vessels to be determined on a population wide scale. Chapter 5 contains the results of this survey and is in the form of a paper prepared for submission to *Notornis*.

While the survey at sea provided information on the birds' relationship to the West Coast hoki fishery on a species-wide scale, it could not reveal whether or not birds differed in their attraction to fishing vessels, the proportion of time that birds spent foraging around vessels, or locations outside of the survey area where Westland petrels forage. Nor could the survey differentiate between non-breeders and the breeding birds of most interest in this study. Tracking individual birds at sea was needed. VHF radio tracking was attempted early on in the study but proved unsatisfactory because birds travelled too far. Satellite tracking methods were then developed and these are described in a paper submitted to *Marine Ornithology* which forms Chapter 6 of this thesis. Satellite tracking allowed breeding birds to be tracked at sea and the proportion of time that they spent in the vicinity of fishing vessels to be assessed. The results of the satellite tracking phase of this research are reported in Chapter 7 which was prepared initially as a report to the Department of Conservation (Lincoln University Wildlife Management Report No. 10).

Based on the results of the previous chapters, Chapter 8 discusses the importance of waste, particularly from the WCSI hoki fishery, in the diet of Westland petrels and assesses the implications for Westland petrels of possible changes in fisheries practices. Recommendations are made for further research which would improve the ability to predict the effects of such changes.

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Chapter 2.

General Methods

The methods specific to particular components of this research are outlined in the appropriate chapters of this thesis. This chapter provides a brief history of this research and outlines methods which will not be described elsewhere in order to more fully document the methodology and explain some of the limitations and difficulties encountered.

During the 1990 and 1991 hoki fishing seasons, I was employed as a MAF Fisheries Scientific Observer on foreign fishing and refrigerated cargo vessels operating on the West Coast South Island fishing grounds. Over this time, the idea for this research was formed, and the background information and personal observations presented in this thesis owe much to my time at sea.

In 1993 I began the diet sampling component of this study at the Scotchman's Creek sub colony which had been monitored for 20 years by J.A. (Sandy) Bartle. Diet sampling was carried out in the months August - October in 1993 - 1996 inclusive. Radio-tracking was tested in July 1993 and the survey at sea was undertaken in August 1993. In 1995 satellite tracking began. Transmitter packages were tested in June and tracking commenced in August 1995. In 1995 and 1996, satellite tracking was carried out at the same time as diet sampling and monitoring of burrows with automatic cameras.

The steep study site, with its fragile burrows and wet climate, placed limitations on the timing and duration of fieldwork. It was necessary to restrict movement around the study colony to avoid breaking burrows and trampling vegetation. The study burrows (see below) were situated on a rough track which runs through the study site and movement was restricted to the track wherever possible. When obtaining diet samples (see Chapter 3) it was often necessary to go off the track on to steep, slippery slopes. To limit damage to the colony this was only practicable on nights when it was not raining.

As burrows would have to be monitored more regularly and some set aside as controls when satellite tracking commenced in 1995, the study burrows previously established by Sandy Bartle, most of which did not have inspection lids, had to be made more accessible, and increased in number.

In January and February 1995, when birds were absent from the colony, 60 burrows were fitted with lids made from plastic screw top sewer inspection pipes, with an internal diameter of 160mm, manufactured by Marley/Hardy Iplex (Fig. 1). First, the position of the nesting chamber was determined. Then a hole was dug down from the surface and fitted with an appropriate length of pipe. These lids were simple to install and provided easy access to the nesting chamber. They were secure against predators, virtually indestructible and did not let in light or cause excessive condensation. They did not alter the shape of the burrow, and can be moved if the nesting chamber shifts. Although many studies of burrowing species have used inspection lids, these have mainly been improvised from plugs of earth, pieces of wood, or other undurable materials. I considered the plastic sewer inspection pipes a marked improvement and they proved indispensable in this study where birds needed to be sighted and handled frequently.

Figure 1. Burrow inspection lid installed in a Westland petrel burrow (photo Frances Schmechel).

Throughout this study, "fences" of toothpicks constructed across burrow entrances were used to detect movements in and out of burrows. This assisted in detecting changeovers during incubation (monitored during model satellite transmitter trials, see Chapter 6) and determining foraging trip lengths. However, automatic cameras installed at burrow entrances (see below and Chapter 7) showed that fences were often disturbed by other animals (eg possums *Trichosurus vulpecula*, rats *Rattus rattus*, weka *Gallirallus australis*) and that birds occupying a burrow would sometimes leave for short periods or sit at the burrow entrance. Therefore, when fences were disturbed, the cause was often uncertain.

In order for sex to be determined without handling birds during burrow inspections, to distinguish individuals in photographs from automatic cameras (see below and Chapter 7) and to identify study burrow birds as they landed at the colony, birds were marked with white enamel paint on their wings and head; males with stripes, females with spots (Fig. 2). The paint was dried with a portable hair drier before the birds were returned to their burrows. Attempts to mark the bird's bills with paint were unsuccessful as the paint quickly wore off.

Figure 2. Westland petrel showing the wing and head markings which identify it as a male. This bird is fitted with a model satellite transmitter taped to its' back. The white tube is a simple depth gauge (see below and Chapter 6) (photo Frances Schmechel).

Trailmaster® (TM 1500) automatic camera and event recording systems were used to record the foraging trip lengths of a sample of birds not tracked by satellite (see Chapter 7). As a bird entered a burrow where a Trailmaster® was installed, it broke an infra red beam which triggered a camera positioned nearby and recorded the time and date on the event recorder (Fig. 3).

Figure 3. Trailmaster® event recorder at a Westland petrel burrow (photo A.B. Freeman).

It took several attempts to get the Trailmaster® systems working effectively at Westland petrel burrows. Consideration had to be given to several factors; securing the equipment so it could not be disturbed by possums, ensuring moving or falling vegetation did not trigger the camera excessively, setting the camera delay to avoid repeat photographs of the same event, and placing the equipment to avoid recording petrel "passers by". Once these problems were solved however, the Trailmaster® systems provided effective burrow monitoring. It should be noted that the manufacturers do not guarantee that dates and times from the cameras' date back, used to match event records with photographs, will print on black and white film. Black and white film was used in this study to keep processing costs to a minimum. "Proof-sheets" proved satisfactory for examining the content of photographs. Although the date and time were often not printed, this was overcome by placing the camera so that the event record number on the event recorder would be visible in the photographs.

Although the Trailmaster® systems were effective, their cost meant that only three units could be purchased and hence only three burrows could be monitored at a time. In an attempt to increase the number of burrows that could be monitored, trap doors installed in burrow entrances were tested. The trap doors consisted of a sturdy wire frame, with a hard plastic flap secured in burrow entrances (Fig. 4). Birds could enter the burrow but, having triggered the trap door, could not leave. The intention was to check burrows with trap doors at regular intervals throughout the night and thus detect when birds returned to their burrows.

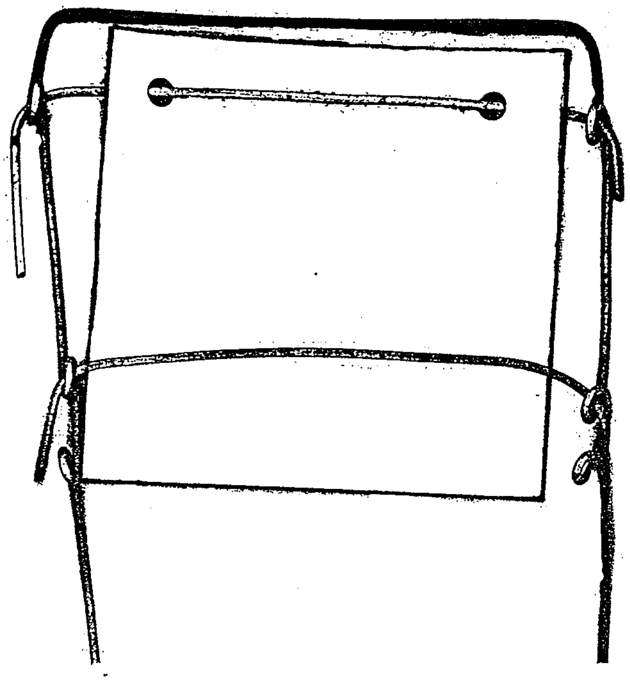

Figure 4. Design of trap door trialed on Westland petrel burrows.

However, two problems, encountered during an initial trial, meant that the trap doors were not used. First, birds often sat outside their burrow when a trap door was installed and would not enter; if they did enter their burrow, they would often dig their way out around the trap door. Second, to determine trip lengths, trap doors would have to be set, and burrows checked throughout every night for at least two weeks. Given the difficulty and hazards of working on the colony in wet weather, this was not practicable.

The methods used to survey the distribution of Westland petrels off the West Coast of the South Island are discussed in Chapter 5. A photograph of the bridge of the *Tangaroa,* the vessel from which the survey was conducted, is included here to show the excellent conditions for surveying afforded by the bridge's extensive windows (Fig. 5).

Figure 5. The bridge of the NIWA vessel *Tangaroa.*

Early on in this research, attempts were made to radio track Westland petrels from land based VHF receiving stations. This work is described in Chapter 6 but as that chapter was prepared as a paper, space did not allow photographs of the radio tracking stations to be included. The radio receiving stations were fitted with revolving antennae to detect signal direction for triangulation between the two stations which were in radio contact (Figs. 6 & 7). Despite the height of the receiving stations, 831m and 1038m, Westland petrels were beyond reception range most of the time they were radio tracked.

Figure 6. VHF radio receiving station on Paparoa Peak near Greymouth, established by Lincoln University to investigate fur seal movements and used in the Westland petrel radio tracking trial.

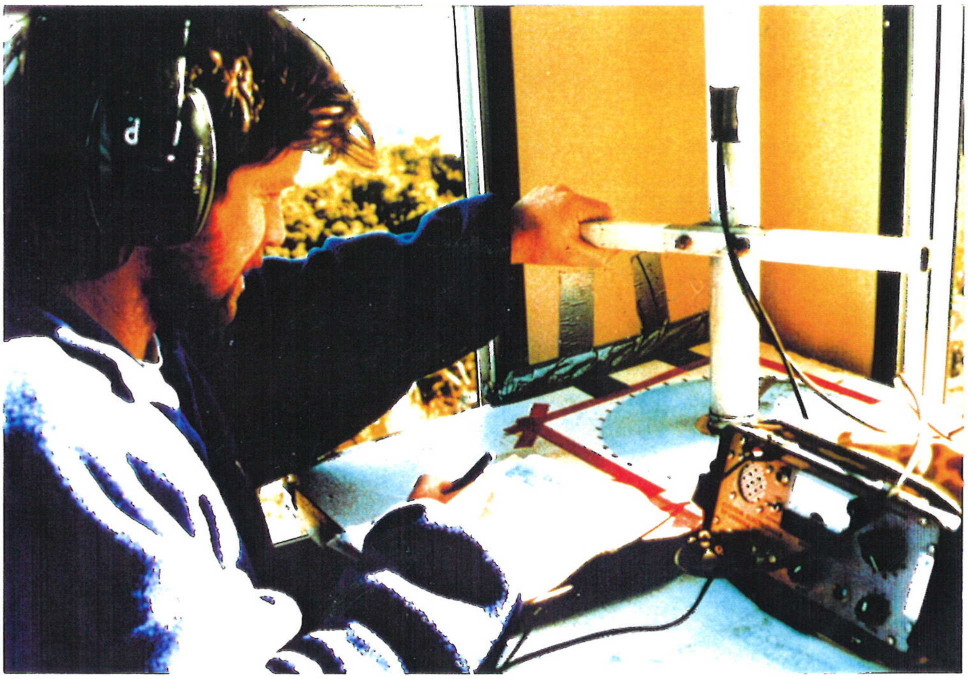

Figure 7. Inside the Paparoa Peak station, Alastair Freeman operates the radio tracking equipment. The revolving antennae and compass rose allow the direction of signals to be determined for triangulation.

As VHF radio tracking proved unsatisfactory, satellite tracking was investigated. The testing procedures involved trialing differently shaped model satellite transmitter packages (see Chapter 6). The model transmitters were made to be as realistic as possible in terms of size, weight and angle of the antennae. Simple depth gauges were taped to the model transmitters to establish how deep Westland petrels dive, as the real satellite transmitters would have to be water proof to this depth (Fig. 2).

All of the methods outlined above, and others described in subsequent chapters of this thesis, were approved by either the Lincoln University Ethics of Experimentation on Animals Committee (Application No. 538) or the Department of Conservation Animal Ethics Committee and operated under the conditions set by the Department of Conservation (Permit Nos: 11/143, 11/153, 11/191, 11/206).

Prepared for submission to *Emu*.

Chapter 3.

The diet of Westland petrels and the importance of fisheries waste during the chick-rearing period

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Abstract

The diet of the Westland petrel *Procellaria westlandica* was studied during the chick-rearing period (August-October) from 1993-1996. Fish occurred in 92% of samples and formed 78.8 ± 6.5% (95% confidence limit) by weight of the solid food brought back to the colony. Cephalopods were found in 32% of samples and contributed 18.7 ± 6.2% (95% confidence limit) of solid food by weight. Crustacea occurred in only 4% of samples and contributed only 2.4 ± 2.4% (95% confidence limit) of solid food by weight. During the part of the chick-rearing period in which the hoki *Macruronus novaezelandiae* fishery was operating (August - mid September), fisheries waste accounted for 80% of the fish found in samples and may have formed 58 - 68% of the total diet at that time. After the hoki season, fisheries waste accounted for only 31% of the fish found in samples, therefore contributing only 22.5 - 26.5% of the total diet as birds switched to more natural prey, or scavenged a wider variety of fish species, presumably from smaller, inshore fishing vessels.

Introduction

Westland petrels *Procellaria westlandica* are burrow-nesting seabirds that breed only near Punakaiki on the West Coast of New Zealand. During their winter breeding season they forage over temperate waters immediately north of the

Subtropical Convergence in the Tasman Sea and through Cook Strait into seas east of New Zealand between 40 and 44° S (Bartle 1974). The total Westland petrel population is now estimated at 20 000 (Marchant & Higgins 1990), a large increase on the 1972 estimate of 6 000-10 000 (Bartle 1974). It has been suggested that this larger population is a result of increased food in the form of waste from fishing vessels (Bartle 1985, 1987). The objective of this study was to determine the composition of the Westland petrel's diet and to assess the importance of fisheries waste to Westland petrels during the chick-rearing period.

There has been little previous research on the diet of Westland petrels. As with other *Procellaria*, cephalopods have been considered a major component of their diet (Prince & Morgan 1987). Imber (1976) found squid (89.5% of items), some fish (10.5%) but no planktonic crustacea in a sample of 12 Westland petrel stomachs (proventriculi and gizzards) collected in July 1969.

Ainley & Boekelheide (1983) observed Westland petrels taking most of their food by surface-seizing, but occasionally Westland petrels have been seen pursuit-plunging (Harper *et al.* 1985). Dives down to a depth of 13 m have been recorded for the closely related white-chinned petrel *Procellaria aequinoctialis* (Huin 1994) and depth gauges deployed on Westland petrels have shown that they are capable of diving to at least 8 m (see Chapter 6). As far as natural prey are concerned, Westland petrels are restricted to those species that spend at least some time in surface waters.

In the late 1950s few Westland petrels had been reported scavenging around fishing boats but in the following decade the number feeding on the Cook Strait trawling grounds greatly increased (Bartle 1974). Today Westland petrels are frequently observed feeding on waste from West Coast hoki trawlers and other fishing vessels (Marchant & Higgins 1990).

The hoki fishery, which developed in the 1970s, is now New Zealand's largest commercial fishery in terms of total catch. Around 100 000 t is currently caught in the West Coast hoki fishery, and 40 000 t in the Cook Strait hoki fishery (S. Ballara pers. comm.) between June and September each year, coinciding with Westland petrel incubation and early chick-rearing. The hoki fishery produces large quantities of waste. In 1986 for example, 23 000 t of waste (37% of the catch) was discharged from the West Coast fishing fleet (Livingston & Rutherford 1988).

It is difficult to demonstrate clear links between seabird population changes and fisheries. It is clear however, that for some species, fisheries waste now forms a significant part of the diet. For example, Jackson (1988) found that trawler offal was the dominant food by mass of the white-chinned petrel in the southern Benguela region, South Africa. It has been suggested that, if a large enough proportion of a species' population comes to depend on scavenging at fishing vessels, there is potential for modification of that species' foraging behaviour, diet and survival (Abrams 1983). In such species, a change in fishing activity could affect that species' population size.

Methods

Food samples were collected from adult Westland petrels at their breeding colony each month over the chick-rearing period (August-October) in 1993-1996. Adult birds returning to the colony were captured immediately after they had landed. During 1993 and 1994 a total of 20 samples was collected from birds which regurgitated when they were inverted over a polythene funnel with a plastic collecting jar attached. In 1995 and 1996 water offloading, where water is introduced into the proventriculus to displace food (Wilson 1984), was used as it had become apparent that individual birds differed in their willingness to regurgitate. A plastic "squeeze bottle" was used to force water into the proventriculus, via a flexible plastic tube with a 5 mm internal diameter. Flushing was repeated until the vomited water was clear, indicating that the stomach was empty (Ryan & Jackson 1986); usually two or three applications of approximately 200 ml. A total of 77 samples was collected over the chick-rearing periods August-October 1995 and 1996. Five regurgitations collected in other months, and four stomachs from dead birds were also examined, giving a total of 106 samples. The mean weight of regurgitated and water-offloaded samples was compared using a two-sample t-test.

Study burrows with chicks, 15 in 1995 and 8 in 1996, were selected in August of each year and adults in these burrows marked with dots of white enamel paint to aid recognition of study burrow birds. These birds were targeted for diet sampling and were also used in satellite tracking (Chapters 6 and 7). To provide a control for the effects of handling, other burrows with chicks (11 in 1995 and 10 in 1996) were selected and birds in these burrows were not diet-sampled or used in other trials. Faced with increased energetic demands, adult petrels should maintain their own nutritional condition at the expense of their chick (Mauck & Grubb 1995). We would therefore expect any detrimental effects of diet-sampling to be reflected in the condition of chicks. Burrows were selected from a pool of 60 burrows fitted with inspection lids before the start of the 1995 breeding season (Chapter 2).

Adults from the study burrows could not provide an adequate number of diet samples. Therefore, samples were also obtained from other birds landing at the colony. Their breeding status was not known. Birds were not caught in the area containing the control burrows and this area was entered as seldom as possible. As birds typically land within a few metres of their burrow, it is unlikely that control burrow birds were sampled accidentally. All birds that were sampled were sexed by examination of their cloaca[1].

Immediately after collection, any lumps of fish flesh were removed from the samples, rinsed in fresh water and set aside for electrophoretic analysis. All samples were frozen at -20° C (usually 4 - 6 hours after collection) until they were sorted. Fish samples for electrophoretic analysis were transferred to a -80° C freezer on return to the laboratory (up to 14 days later).

Samples were later defrosted then washed and drained through a 600 *u*m Endocott sieve. They were then weighed and sorted into the main prey categories of fish, cephalopods and crustacea. Cephalopod beaks, fish otoliths, crustacea and other potentially identifiable remains (e.g. fish jaw bones and scales) were preserved in ethanol for later analysis. Highly digested material was weighed and divided proportionately amongst the identified fractions. The mean percentages of the major prey categories are presented ± 95% confidence limits. Means were compared between years and months using one-way analyses of variance and Bonferroni pairwise comparisons of means, and

[1] In Westland petrels it is possible to sex adults throughout the breeding season by examination of the cloaca (J.A. Bartle unpublished data; pers. obs.).

between sexes using a two-sample t-test. The frequencies of occurrence of the major prey categories were compared between months and between sexes using Chi-square tests.

Few fish were sufficiently undigested to be identified by their external appearance. Fish identification was therefore almost entirely based on otoliths and electrophoresis. Fish otoliths were identified by myself, M.J. Imber (DOC[2]) and P. McMillan (NIWA[3]) by comparison with reference material held at CSIRO[4], Hobart and DOC, Wellington, and by reference to Lalas (1983) and Williams & McEldowney (1990). Relatively intact fish were identified by A. Stewart (MONZ[5]). Fish sizes (Table 1) were determined from formulae provided in Lalas (1983), from published size ranges (Ayling 1982), or by extrapolating from incomplete specimens. Fish back bones found in the samples, although mostly incomplete, were measured to obtain estimates of the size range of fish eaten. Samples of fish flesh were analysed using the electrophoretic technique iso-electric focusing (IEF) (Chapter 4).

Cephalopod remains included beaks, eye lenses and pieces of gladius and mantle. Beaks were identified by M.J. Imber and the mantle lengths of cephalopods estimated from beak measurements using regression equations published in Clarke (1986). W.R. Webber and J.A. Bartle (MONZ) identified the crustaceans by their exoskeletons.

Samples were categorised as fisheries waste if they were comprised of fish species commonly caught by fishing vessels that would not normally be available to Westland petrels because they inhabit deep water. A sample was categorised as natural prey if it contained fish species readily available to Westland petrels, for example, common surface dwelling or diurnally migrating fish species. The hoki season includes all samples collected between 1 August and 15 September. The post-hoki season includes samples collected after 15 September.

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[2] Department of Conservation, New Zealand
[3] National Institute of Water and Atmospheric Research, New Zealand
[4] Commonwealth Scientific and Industrial Research Organisation, Australia
[5] Museum of New Zealand

Just prior to fledging, in November 1995 and 1996, chicks in study and control burrows had their wing lengths (flattened wing chord) measured and were weighed with a Pesola spring balance.

Results

The mean weight of all samples (drained) was 37.97 ± 5.15 g. There was no difference between the mean weights of regurgitated and water-offloaded samples so these data sets were combined (t = 1.11; P = 0.27). Fish comprised the major prey category (Fig. 1).

The mean percentage of fish in all regurgitated and water-offloaded samples (N=102) was 78.8 (± 6.5) %; cephalopods 18.7 (± 6.2) %; and crustacea 2.4 (± 2.4) %. Fish occurred in 92%, cephalopods in 32% and crustacea in 4% of samples. Sixty-four percent of samples contained only fish (Fig. 2).

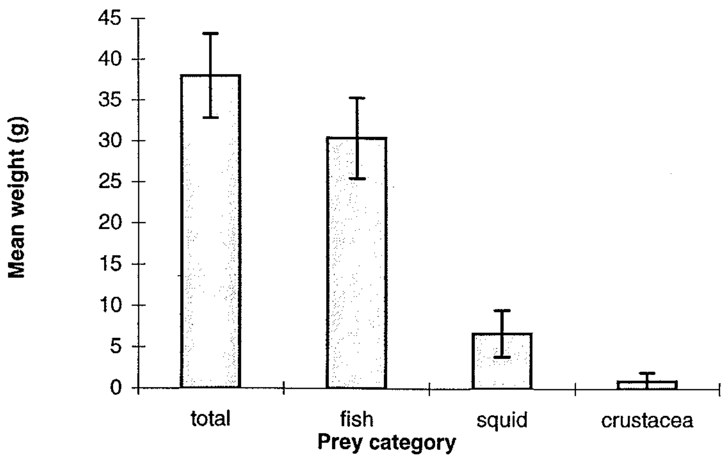

Figure 1. Mean weight of all Westland petrel diet samples and of the major prey categories (means presented ± 95% CI, N = 102 stomach samples).

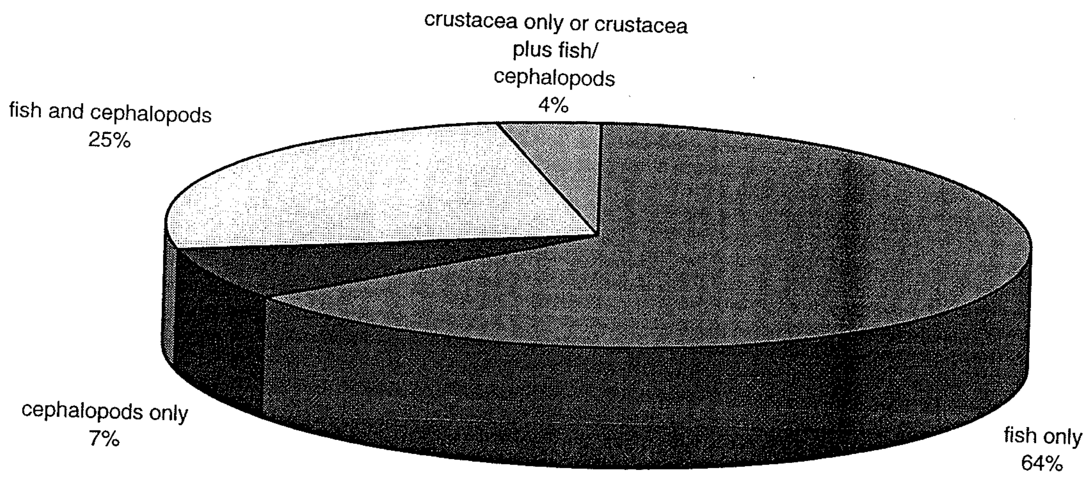

Figure 2. Composition of Westland petrel diet samples (N = 102).

There was no change in the frequency of occurrence of the major prey categories over the chick-rearing period (fish, $\chi^2 = 0.2$, $P = 0.9$; cephalopods, $\chi^2 = 0.87$, $P = 0.64$; crustacea, $\chi^2 = 0.28$, $P = 0.6$). Nor was there any difference in the frequency of occurrence of the major prey categories between males and females (fish, $\chi^2 = 2.86$, $P = 0.09$; cephalopods, $\chi^2 = 0.12$, $P = 0.73$; crustacea, $\chi^2 = 0.49$, $P = 0.45$).

The weight of diet samples increased as the chick-rearing period progressed from a mean of 30 g in August to a mean of 47 g in October (Fig. 3).

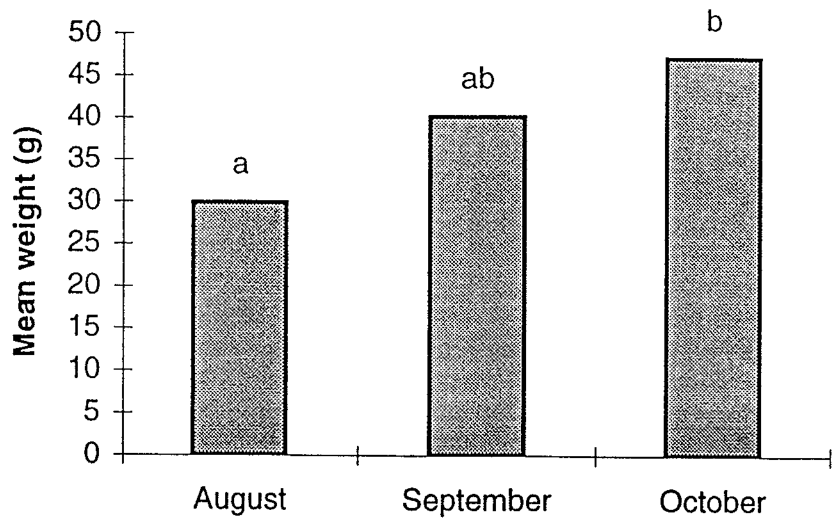

Figure 3. Mean weight of Westland petrel diet samples over the breeding season (letters indicate means that differ significantly P<0.05, N=97).

The prey items identified from their external appearance or hard parts (fish otoliths, cephalopod beaks) are shown in Tables 1 and 2. Macrourids and myctophids were the commonest fish remains and histioteuthids and cranchiids the commonest cephalopod beaks encountered in the samples. Few identifiable hard parts were found as most samples were well digested. Of the 93 samples in which fish occurred, otoliths were present only in 14. Cephalopod beaks were found in only 14 of the 37 samples which contained cephalopod remains. These beaks were from specimens estimated to be between 38 and 197 mm in mantle length (Table 2).

Table 1. Fish species in Westland petrel diet samples identified from otoliths, jaw bones and external appearance.

Taxon	A[1]	No.	B[2]	Size (mm)[3]	Source of size estimate
Ophichthidae					
Muraenichthys sp	C	1	N	230 TL	Measured specimen
Clupeidae					
? *Sprattus* sp	O	1	N	84 FL	Lalas' (1983) equation for *S. antipodum*
Engraulidae					
? *Engraulis australis*	O	1	N	80-140 TL	Adult size (Ayling 1987)
Photichthyidae					
Photichthys argenteus	O	1	N	200-250 TL	Adult size (A.Stewart pers. comm.)
Myctophidae	O	2	N		
Lampanyctus australis	O	2	N	50-100 TL	Adult size (Ayling 1987)
Moridae					
Auchenoceros punctatus	O	1	N	119 TL	Lalas' (1983) equation
Pseudophycis sp	P	1	W	400 TL	Estimated from specimen
Merlucciidae					
Macruronus novaezelandiae	O	2	W	323-325 TL	Lalas'(1983) equation
Macrouridae	P	1	W	200-300 TL	Estimated from specimen
Caelorinchus sp	O	2	W	172 TL	Lalas' (1983) equation
Lepidorhynchus denticulatus	O	2	W	200-500 TL	Adult size (Ayling 1987)
Zeidae/Oreosomatidae	O	1	?		
Cyttus sp	P	1	N	20 TL	Estimated from specimen
Scorpaenidae					
? *Helicolenus* sp	O	1	N	60 TL	Lalas' (1983) equation for *H. papillosus*
Triglidae					
? *Chelidonichthys kumu*	P	1	W	180 FL	Estimated from specimen
Gempylidae/Trichiuridae	J	1	W		

[1] Specimen type; C=complete fish , J=jaw bones, O=otoliths, P=partial fish.
[2]Probable source of food item; N=natural prey, W=fisheries waste. [3] L=total length, FL=fork length.

Table 2. Cephalopod and crustacean species in Westland petrel diet samples identified from beaks and exoskeletons.

Taxon	No.	Occurrence	Estimated sizes (mm)[1]	Source of size estimate
Cephalopoda				
Gonatidae				
Gonatus antarcticus	2	2	197	Clarke (1986) *Gonatus*
Histioteuthidae				
Histioteuthis macrohista	4	3	38, 55	Clarke (1986) Histioteuthidae
Histioteuthis atlantica	6	4	53, 53, 77, 78	Clarke (1986) Histioteuthidae
Mastigoteuthidae				
Mastigoteuthis sp.	1	1		
Cranchiidae				
Taonius sp.	1	1		
Teuthowenia pellucida	4	4		
Spirulidae				
Spirula spirula	2	2	55	Clarke (1986)
Octopodidae				
Octopus cordiformis	1	1	157	Clarke (1986) Octopodinae
Crustacea				
Euphausiidae				
Nyctiphanes australis	1076	4	13-17	All crustacea estimated
Thysanoessa gregaria	5	1	15	from measurements of
Caridea	1	1	26	intact or partial specimens
Notostomus auriculatus	1	1	47	
Cymothoidae	2	1	40	

[1] Lengths given are mantle length for cephalopods and total length for crustacea.

Of the 18 samples which produced satisfactory, potentially identifiable banding patterns after electrophoresis, at least ten were probably scavenged from fisheries waste (Table 3). These species would not normally be available to Westland petrels because they are deep water species. The remainder, which could not be identified did not match any of the commercial fish or bycatch species that they were compared with, and in the following analyses are presumed to have been naturally acquired prey (Chapter 4).

Table 3. Fish species from Westland petrel diet samples identified by the electrophoretic technique iso-electric focusing.

Species Identification	Number (n=40)	Source
Macruronus novaezelandiae	4	Fishery waste
Lepidorhynchus denticulatus	2	Fishery waste
Caelorinchus sp.	4	Fishery waste
Unidentified	8	Natural prey?
Indeterminate[1]	22	

[1] These samples were too degraded to be identified using IEF.

Combining all identification methods, fisheries waste was found to be the largest source of fish during the winter hoki fishing season, but natural fish prey accounted for most fish eaten after the hoki season had ended. During the hoki season, fisheries waste comprised 58 - 68% of the total diet, and continued to provide 23 - 27% of the diet after the hoki season had ended (Table 4).

Fisheries waste was found in food samples from both male and female Westland petrels. Of those food samples which contained fisheries waste, 13 were from sexed birds, eight males and five females.

Table 4. Source of fish consumed by Westland petrels and the contribution of fisheries waste to the diet during and after the hoki fishing season.

Season	Fisheries Waste						Natural Fish Prey						No.
	a	b	c	T	%	%D	a	b	c	T	%	%D	
Hoki	5	2	1	8	80	**58 - 68**	1	1	0	2	20	**15 - 17**	10
Post-hoki	3	4	1	8	31	**23 - 27**	7	11	0	18	69	**50 - 59**	26

a=samples identified by electrophoresis, b=samples identified by otoliths or external features, c=samples identified from both otoliths and electrophoresis. T=total, %=percentage of identifiable fish samples, %D= potential contribution to total diet, given that fish comprises 79 $\pm$ 6.5% of the diet.

Identifiable natural fish prey measuring up to 230 mm long were found in diet samples (Table 1). Fifty-nine fish vertebrae sections were measured, and although incomplete, six had a length $\geq$ 100 mm. The longest vertebrae section measured 180mm. These measurements and the estimated sizes calculated in Table 1, suggest that Westland petrels prey on fish in the 50 - 230 mm size range. Size estimates above this length are for species probably scavenged from fisheries waste and were most likely incomplete when eaten (Table 1).

The prefledging weight and wing length measurements of study burrow chicks whose parent(s) had had at least one diet sample taken from them are compared with control burrow chicks in Table 5. Chicks missed at most one meal per month (August - October) during the diet sampling.

Table 5. Comparison of study and control burrow chicks.

	Fledging success in 1995	Mean weight(g)/ wing length (mm) 15/11/1995	Fledging success in 1996	Mean weight(g)/ wing length (mm) 11/11/1996
Study	67% (n=15)	1536/338 (n=7)	100% (n=9)	1736/320 (n=7)
Control	64% (n=11)	1486/329 (n=7)	100% (n=10)	1930/325 (n=10)
significance		not significant weight t=0.46,P=0.65 wing t=0.39, P=0.7		not significant weight t=1.75, P=0.1 wing t= 0.46, P=0.65

There were no significant differences between study and control chicks for fledging success, weight or wing length. Loss of 1-3 meals over the August-October period apparently did not adversely affect these chicks.

Discussion

The most notable feature of the diet of Westland petrels as shown by this study is the predominance of fish. Fish is much more important than indicated by Imber's (1976) study, and forms a higher proportion of the diet than that recorded in most other studies of *Procellaria* (eg Cooper *et al.* 1992; Croxall *et al.* 1995).

Seabird diet studies have traditionally relied on identification of prey hard parts found in diet samples. Much fisheries waste however, does not have any identifiable hard parts. In this study, electrophoresis of fish tissue allowed more fish samples to be identified than would otherwise have been possible.

The large proportion of fish found in this study is largely attributable to fisheries waste. The fish species discharged as waste are predominantly slope dwelling, middle water fishes (approx 300-600 m) of the families Macrouridae (rattails), Merluccidae (hoki, hake), Ophidiidae (ling), and Moridae (morid cods) which would otherwise be unavailable to Westland petrels which, like the closely related white-chinned petrel, probably dive no deeper than 15 m. The presence of such species as hoki, the rattails *Caelorinchus* sp. and *Lepidorhynchus denticulatus,* and the morid cod *Pseudophycis* sp. among Westland petrel diet samples is therefore an indication of widespread scavenging. Both males and females exploit fisheries waste, and during the hoki fishing season it may contribute as much as 58 - 68% by weight of the diet.

Given the size of the hoki fishery, it was expected that, if this were important to Westland petrels, the proportion of fish in the diet should decrease after the hoki fishing season ended in September. This did not occur, however, and the proportion and occurrence of fish remained constant over the August - October chick-rearing period. Although hoki and other species probably derived from hoki fishery waste dominated during the hoki season, once the season was finished, Westland petrels changed to other sources of fish. After the hoki season, an estimated 23 - 27% of their food was still derived from fisheries waste, presumably scavenged from the smaller inshore fisheries (eg fish identified as cod *Pseudophycis* sp, gurnard *Chelidonichthys kumu*, and barracouta *Thyrsites atun*/gemfish *Rexea solandri*; all species commonly caught by vessels fishing off the West Coast). They also consumed more naturally acquired fish prey such as myctophids, clupeids and engraulids.

The natural fish prey identified in the diet of Westland petrels were predominantly small species common over the continental shelf and slope where Westland petrels typically forage (Marchant & Higgins 1990). Myctophid fishes were the commonest natural fish prey. These fishes undertake diurnal vertical migrations moving up toward the surface at night to feed on planktonic animals. They have a high energy content (Cherel & Ridoux 1992), making them particularly valuable prey.

Imber (1976) found *Histioteuthis*, *Teuthowenia pellucida*, and *Chiroteuthis* of the families Histioteuthidae, Cranchiidae and Chiroteuthidae respectively to be the most frequently occurring cephalopods in Westland petrel stomach remains. In that paper (Table 3 in Imber 1976) *Megalocranchia richardsoni* is a deposed name for *Teuthowenia pellucida*, and the *Enoploteuthis* beaks, which were very degraded beaks from gizzards, have also since been identified as *Teuthowenia pellucida* (M.J. Imber pers. comm.). The present study also found histioteuthids and cranchiids to be the most common cephalopod families in the diet samples.

A diel vertical migration pattern (rising to surface waters at night) is probably widespread among the Histioteuthidae (Roper & Young 1975). All are bioluminescent and relatively slow-moving and these features, together with their size, make them predisposed to petrel predation when near the surface (M.J. Imber pers. comm.).

The cranchiids have not been shown to exhibit strong vertical migration, but many species exhibit ontogenetic descent where larger specimens inhabit progressively deeper water (Roper & Young 1975). The presence of immature *Teuthowenia pellucida* in Westland petrel diet samples is probably an example of this phenomenon. In its juvenile to sub-adult stages, *Teuthowenia pellucida* migrates to near-surface waters at night, but adults remain in much deeper water (Voss 1985). However, some adults eaten by these petrels may have been scavenged.

Gonatid squids are only of minor importance as food for petrels (Imber 1978). *Gonatus antarcticus*, identified from two Westland petrel diet samples, is an active, non-bioluminescent squid, presumably making it more difficult to catch. It is, however, widely distributed in the southern oceans and relatively abundant in surface waters (Imber 1978).

The spirulid *Spirula spirula* lives at 200-1000 m (Clarke 1986), far beyond the diving capacity of Westland petrels. It is, however, apparently subject to post-breeding die-off during winter (M. J. Imber pers. comm.) and so the specimens found in this study may have been scavenged from surface waters.

There were very few samples containing Crustacea. This supports Lewis' (1969) view that the clear to pale yellow stomach oil observed in Westland petrels is an indicator that Crustacea are a minor part of the diet. *Nyctiphanes australis*, the only species found in large numbers in the diet samples, is the dominant euphausiid species found around New Zealand. It is confined to the uppermost 30 m of the water column in the coastal waters of New Zealand and south-eastern Australia. It is much more abundant at the surface by night than by day (Bartle 1976). *Thysanoessa gregaria* is also diurnally migrating, but is present in much smaller numbers around New Zealand. This is reflected in the very small numbers taken by Westland petrels. The carids are pelagic mid-water shrimps that may also migrate vertically. The cymothoid isopods are fish parasites and were probably consumed incidentally along with fish.

Converting food into proventricular oil allows many Procellariiformes to reduce the mass of the food load they must carry into a highly concentrated source of energy. Oil therefore represents a very important contribution to the nutrition of both chicks and adults, and the prey from which the oil is derived must be considered an important part of the diet. Unfortunately it is not possible to identify specific prey species from which proventricular oil is derived (Horgan & Barrett 1985), and so diet studies of petrels are limited to inferring the total diet from the solid portion of diet samples.

Of the natural prey acquired by Westland petrels, the predominance of fish and squid species, which are only present in surface waters at night, indicate that Westland petrels mainly obtain natural prey then from the highly productive waters of the shelf break. This pattern of behaviour may have led to an over- estimation of fish and fisheries waste in this study as most diet samples were taken in the evening and any natural prey consumed the night before would be more digested than waste scavenged during that day.

The importance of cephalopods in the diet may also be underestimated by the methods employed in this study. Samples from birds induced to vomit do not contain any gizzard contents and this probably accounts for the differences in the relative importance of fish and squid in this and Imber's (1976) study of Westland petrel samples collected in 1969. Imber (1976) used hard remains from gizzards (the proventriculi of his specimens were mainly empty, M.J. Imber pers. comm.) which can make less readily digested prey appear more important than prey that is quickly digested (Hyslop 1980). For example, fish otoliths are digested quickly in seabird stomachs (Duffy & Laurenson 1983), compared with cephalopod beaks which accumulate and persist in the gizzard (Furness *et al.* 1984). Conversely, the proventricular contents obtained from regurgitations and water-offloading in this study may have underestimated the importance of squid. The difference could

also be partly due to an increase in the quantity of fish eaten by Westland petrels between the late 1960s and the present due to the development of the hoki fishery. Many similar fish species, but no hoki, were found in Imber's (1976) study.

Although the incidence of fisheries waste in the Westland petrel diet may have been overestimated by the methods employed in this study, it is clear that fisheries waste is an important component of the solid food brought back to the colony. It may form more than half of the diet during the hoki fishing season, and around a quarter of the diet after the hoki season has ended.

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Chapter 4.

The use of iso-electric focusing in the identification of fisheries waste in the diet of Westland petrels *Procellaria westlandica*

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Abstract

Iso-electric focusing was used to identify fish tissue in Westland petrel *Procellaria westlandica* diet samples that could not otherwise be identified. Forty-five percent of the tissue samples from Westland petrel stomachs produced acceptable protein banding patterns and more than half of these were identified as species common in fisheries waste. Proteins in the other samples were presumably too digested for this technique to work. Although other methods, which do not rely on proteins (ELISA; DNA analysis), may permit a higher proportion of diet samples to be identified, iso-electric focusing is a comparatively quick and inexpensive technique and is worth considering for diet studies where at least some food is likely to be relatively undigested.

Introduction

Westland petrels *Procellaria westlandica* breed only near Punakaiki on the West Coast of New Zealand. During their winter breeding season they forage mainly over the continental shelf and slope off the west coast of the South Island of New Zealand (Marchant & Higgins 1990). Here they encounter the large scale West Coast hoki *Macruronus novaezelandiae* fishery and several small scale fishing operations. These fisheries produce large quantities of waste which are scavenged on by many species of seabirds. The waste discharged is typically comprised of middle depth and deep water fish species that would not normally be available to surface feeding seabirds such as Westland petrels.

The close proximity of the large scale hoki fishery to the Westland petrel's breeding colonies and reports of Westland petrels scavenging at fishing vessels, led to the hypothesis that fisheries waste forms a significant part of the Westland petrel's diet. The Westland petrel population has increased significantly in recent decades, and it has been suggested that this has been partly a result of increased food in the form of fisheries waste (Bartle 1985; 1987). Until now there have been no diet studies to test this question.

Residual hard parts from whole prey, such as fish otoliths and squid beaks can often be identified by comparison with reference material, keys and photographic guides (eg Clarke 1986; Williams & McEldowney 1990). In contrast, the undigested or partially digested tissues which derive from fisheries waste usually provide few external characteristics for identification. Biochemical methods have the potential for detecting species specific markers in digested prey items, but have seldom been used. The ELISA (enzyme-linked immunosorbent assay) has been used for identification of invertebrate tissue (Feller *et al.* 1985; Grisley & Boyle 1985) but requires considerable laboratory effort to produce specific antisera to the range of potential prey species. Preliminary trials to identify fish and molluscan prey of seabirds also noted problems with cross reactivity, where were produced by more than one species (Walter *et al.* 1986).

Iso-electric focusing (IEF) of muscle proteins is widely used in fisheries forensics for the species identification of fillets and fish product (Lundstrom 1977; Benson & Smith 1989) and has been tested for its ability to identify flesh samples from seabird stomach contents (Walter & O'Neill 1986). In their study, using PAGE (Polyacrylamide Gel Electrophoresis) to identify prey consumed by captive held jackass penguins *Spheniscus demersus*, Walter and O'Neill (1986) found that different prey species could be recognised up to six hours after ingestion. High molecular mass proteins showed a breakdown when viewed with densitometer scans, but low molecular mass proteins persisted during digestion. Unfortunately, Walter & O'Neill (1986) did not present photographs of their gels.

The present study appears to be the first time that an electrophoretic technique has been used in a study of the diet of a wild bird. As part of a wider study of Westland petrel diet, we used IEF to identify fish tissue which would not otherwise be identifiable. Here we match specific protein bands of Westland petrel stomach content samples to a range of fisheries waste and natural prey species in an attempt to establish the identity, and therefore the source, of fish consumed.

Methods

Samples of fish tissue were removed from diet samples collected by regurgitation and water-offloading (Wilson 1984) of adult Westland petrels as they arrived at their breeding colony. Tissue samples were rinsed in fresh water and stored individually in plastic bags. They were frozen (-20°C) as soon as possible, but due to other work on the colony this was usually three to four hours and sometimes as much as 14 hours after collection. Samples were later transferred to a -80°C freezer on return to the laboratory. Forty fish tissue samples were collected from Westland petrels between July 1994 and October 1996.

Fish specimens were collected from various voyages of the NIWA[1] vessel *Tangaroa*. The species collected for comparison were those considered likely to occur in Westland petrel diet samples, either because they are prominent amongst

trawler waste, have been previously identified in the Westland petrel diet (Imber 1976), or are common in surface waters where Westland petrels forage during their breeding season (Table 1). Unfortunately we were unable to obtain specimens of *Caelorinchus bollonsi*, a very common rattail, or *Maurolicus muelleri*, a very abundant mesopelagic lightfish, which we considered likely to occur in the Westland petrel diet.

[1] National Institute of Water & Atmospheric Research

Table 1. Fish species used as comparisons in iso-electric focusing of Westland petrel stomach contents.

Species	Common in fisheries waste	Previously identified in Westland petrel diet	Common in surface waters
Macruronus novaezelandiae (hoki)	x		
Merluccius australis (hake)	x		
Genypterus blacodes (ling)	x		
Seriolella punctata (silver warehou)	x		
Thyrsites atun (barracouta)	x		
Lepidorhynchus denticulatus (javelin fish)	x	x	
Caelorinchus aspercephalus (rattail)	x		
C. fasciatus (rattail)	x		
C. biclinozonalis (rattail)	x		
C. subserrulatus (rattail)	x		
C. oliverianus (rattail)	x		
Argentina elongata (silverside)		x	
Photichthys argenteus (lighthouse fish)		x	
Lampanyctus sp. (lanternfish)			x
Lampanyctodes hectoris (lanternfish)			x
Symbolophorus sp. (lanternfish)			x
Engraulis australis (anchovy)			x
Sardinops neopilchardus (pilchard)			x

The iso-electric focusing methods used are described in detail in Benson & Smith (1989). Iso-electric focusing of muscle extracts from the 40 Westland petrel diet samples and the 18 known species was performed in wide range (pH 3-10) agarose gels. A small piece (approx 0.5 g) of white muscle from each known species was homogenised in an equal volume of de-ionised water and centrifuged at 11.0 revs for five minutes at 5°C. Pieces of muscle were dissected from the Westland petrel diet samples and treated in the same way. The clear supernatants were absorbed onto filter inserts which were then placed directly onto the agarose gel. IEF and protein staining procedures followed Benson & Smith

(1989). Following IEF and staining, the gels were dried and the number, intensity and position of protein bands from the Westland petrel samples compared to the identified species. Where similarities were found between samples run on different gels, samples were rerun on the same gel to confirm the match.

Results

Iso-electric focusing in wide range gels produced clear patterns of protein bands in all specimens from identified species. No differences were observed in the banding patterns of white muscle samples from individuals of the same species, but there were differences between all species.

Eighteen of the 40 Westland petrel diet samples (45%), all from different birds, produced adequate protein banding patterns. Six of these were positively identified as hoki and javelin fish and four produced banding patterns very similar to the *Caelorinchus* species (Table 2, Fig.1). Eight other samples produced good bands but could not be matched with any of the identified species.

Table 2. Fish tissue from Westland petrel diet samples identified by iso-electric focusing.

Species Identification	**Number** (n=40)	**Probable Source**
Macruronus novaezelandiae (hoki)	4	Fishery waste
Lepidorhynchus denticulatus (javelin fish)	2	Fishery waste
? *Caelorinchus* sp (rattail)	4	Fishery waste
Unidentified	8	?
Indeterminate[1]	22	

[1]These samples which failed to produce adequate banding patterns were presumably too degraded for IEF.

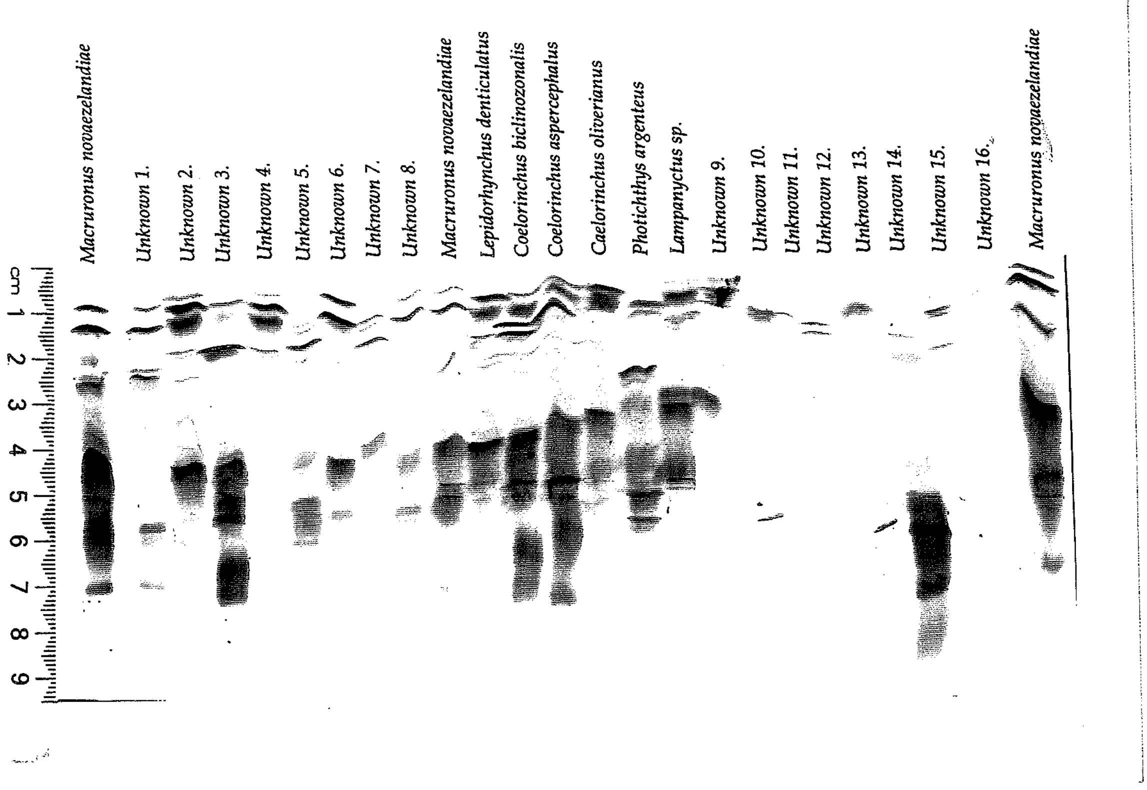

Figure 1. Example of a dried agarose gel showing matching of protein bands between Westland petrel diet samples and hoki *Macruronus novaezelandiae* (unknowns 1, 6, 8) and javelin fish *Lepidorhynchus denticulatus* (unknowns 2, 4).
Unknown 3 is very similar to the *Caelorinchus* species.

Discussion

Iso-electric focusing enabled us to identify ten samples (six positively, four tentatively) of fish tissue from Westland petrel diet samples that would otherwise have been indeterminable. Other samples could potentially have been identified if a more complete range of species were available for comparison. The predominance of hoki, javelin fish, and specimens that were probably rattails, in the identifiable samples lends support to the suggestion that fisheries waste is an important component of the Westland petrel's diet.

Electrophoresis is suitable only for relatively undigested prey since proteins lose their characteristic electrophoretic bands as digestion proceeds (Walter & O'Neill 1986). More than half of the fish tissue samples collected from Westland petrel stomachs did not produce adequate protein banding patterns and it is presumed that these were too degraded by digestion. This is not surprising considering the often lengthy period of time between ingestion and eventual freezing of the specimens. Walter & O'Neill (1986) found that prey species could not be recognised more than six hours after ingestion. Although we do not know when the fish from which we obtained samples were eaten, presumably they had often been in the bird's stomach for longer than this as Westland petrels typically undertake foraging trips of up to three days duration (A.N.D. Freeman unpublished data).

Walter & O'Neill (1986) suggest that it may be possible to compare standards from known prey species at various stages of digestion and to use these to identify digested prey species. They acknowledge that this procedure would be labour intensive, and require captive study animals. Although we cannot control digestion that occurs before sampling, some simple improvements to the collection methods presented here, particularly prompt freezing after collection, could help preserve samples so they denature less quickly.

Other techniques (eg ELISA, Walter *et al.* 1986; DNA analysis, Sotelo *et al.* 1993), which do not rely on proteins, are less sensitive to the state of digestion and may permit a higher proportion of diet samples to be identified. Iso-electric focusing is, however, a comparatively quick and inexpensive technique and is worth considering for any diet study where muscle tissue is an important component of diet samples, residual hard parts are infrequent, and at least some food is likely to be relatively undigested.

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Chapter 5.

The influence of fishing vessels on Westland petrel distribution at sea

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Summary

The Westland petrel *Procellaria westlandica* population is thought to have increased significantly in recent decades, perhaps as a result of increased food in the form of waste from fishing vessels. A survey of Westland petrels off the West Coast of the South Island, New Zealand, showed that fishing vessels in the West Coast South Island hoki *Macruronus novaezelandiae* fishery do influence the distribution of Westland petrels, but only a small proportion of the Westland petrel population appears to utilise the fisheries waste resource at any one time.

Introduction

The Westland petrel *Procellaria westlandica* is a large burrowing petrel which only breeds near Punakaiki on the West Coast of the South Island of New Zealand. The Westland petrel population is thought to have increased significantly in recent decades. The total population is now estimated at 20 000 (Marchant & Higgins 1990); a large increase on the 1972 estimate of 6 000-10 000 (Bartle 1974). It has been suggested that this population growth is a result of increased food in the form of waste from fishing vessels which is now assumed to be an important component of their diet (Bartle 1985 and 1987).

In the late 1950s few Westland petrels fed on trawl waste from fishing vessels (Bartle 1974). However, the number feeding on the Cook Strait trawling grounds greatly increased during the 1960s (Bartle 1974). In October/November 1975 Westland petrels were observed feeding on discarded fish offal during exploratory fishing off Greymouth, West Coast (Vooren 1977). This behaviour is considered common today as Westland petrels are frequently seen feeding on waste from West Coast hoki *Macruronus novaezelandiae* fishery trawlers and from other fishing vessels within their range (Marchant & Higgins 1990).

The West Coast hoki fishery is by far the largest of the commercial fishing operations close to the Westland petrel's breeding colonies. The fishery operates from mid June to early September when Westland petrels are incubating eggs and raising chicks. The hoki fishery is New Zealand's largest commercial fishery in terms of total catch. With the discovery of the main hoki spawning area around the Hokitika Canyon, catches reached almost 98 000 t in 1977. The catch peaked at about 220 000 t in 1988 although it has since declined to around 100 000 t per year on the West Coast (Sullivan & Cordue 1992; S. Ballara pers. comm.). Livingston & Rutherford (1988) estimated that during the 1986 fishing season, 37% of the West Coast catch was dumped as waste. Therefore, about 37 000 t may now be discharged annually from the West Coast fishery, although the quantity will vary depending on the composition and characteristics of the fishing fleet from year to year. For example, Livingston and Rutherford (1988) estimated that in the 1985-1986 fishing year, 48% of the catch from surimi vessels was dumped as waste compared to 25% of the catch from non-surimi vessels.

It is difficult to demonstrate clear links between seabird population changes and fisheries. It is clear however that for some species, fisheries waste now forms a significant part of their diet. For example, Jackson (1988) found that trawler offal was the dominant food by mass of white-chinned petrels *Procellaria aequinoctialis* in the southern Benguela region of South Africa. It has been suggested that if a large enough proportion of a species' population comes to depend on scavenging at fishing vessels, there is potential for modification of that species' foraging behaviour, diet and survival (Abrams 1983). In such a species, a change in the level of fishing activity could affect that species' population size. The importance of fisheries waste in the diet of Westland petrels needs to be assessed because fisheries waste on the West Coast may be reduced through the withdrawal of many surimi vessels in favour of smaller filleting vessels and due to an increasing proportion of the hoki quota being caught in Cook Strait and other areas.

The importance of fishing vessels as a source of food can be inferred by comparing the distribution of a species at sea with that of fishing vessels. Ryan & Moloney (1988) for example, compared the distribution of seabirds and seals to that of trawling effort in the southern Benguela demersal trawl-fishery and found that the distribution of some species, including the white-chinned petrel, was significantly influenced by commercial trawling activity. The influence of fishing vessels in the West Coast hoki fishery on the distribution of Westland petrels was investigated during a seabird survey conducted during August 1993. The survey formed part of a larger study on Westland petrel diet and foraging ecology.

Methods

From 2 - 14 August 1993, the MAF[1] Fisheries (now NIWA[2]) research vessel *Tangaroa* conducted acoustic surveys of spawning hoki off the West Coast of the South Island (Fig. 1). The survey included the areas intensively worked by hoki trawlers and coincided with the early chick rearing period when Westland petrels may be most likely to take advantage of the nearby fishery. The *Tangaroa* was not fishing during this period, except for nine short trawls to validate acoustic data. These trawls were mainly at the end of the day and so did not affect the days' counts. Therefore it is assumed that the "attraction" of the *Tangaroa* to birds was constant throughout the voyage.

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[1] Ministry of Agriculture and Fisheries
[2] National Institute of Water and Atmospheric Research

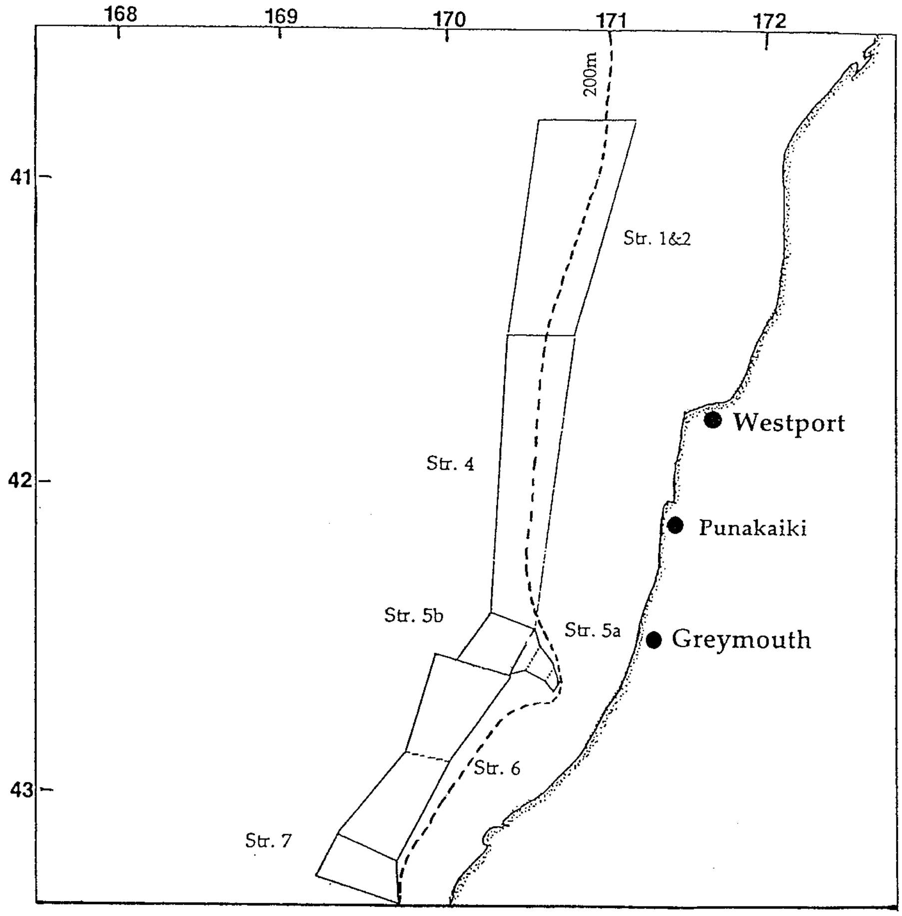

Figure 1. Acoustic survey areas, West Coast, South Island 2 - 14 August 1993. (from Voyage Programme TAN 93/07, P.L. Cordue, MAF Fisheries)

Ten minute counts of seabirds, visible with 8x40 binoculars all around the vessel (360°) to a distance of 500 m, were made every half hour during daylight hours. All birds were recorded but only Westland petrels and unidentified, black *Procellaria* are reported here. Records of Westland petrels and unidentified *Procellaria* were extracted from the counts made over the edge of the continental shelf and inner continental slope (waters 200 to 800 m deep) where Westland petrels generally forage (n=124 counts). Although 46% (38 birds) of all *Procellaria* sightings were unidentified, these were combined with the positively identifed Westland petrel records. The unidentified *Procellaria* could have been white-chinned petrels *Procellaria aequinoctialis.* However as this species is less abundant in the Tasman Sea than to the south and east of New Zealand (Imber 1985), generally forages further out to sea than Westland petrels and was positively identified only once during the survey, it is most likely that the unidentified *Procellaria* recorded were *westlandica.* Counts carried out while the *Tangaroa* was trawling or discharging waste were not included in this analysis.

Immediately before each count, the distance between the *Tangaroa* and other vessels was recorded from the ship's radar and where possible the types of vessels recorded. These data supplemented the trawl data used in the Geographical Information System analysis described below, particularly for small vessels for which no locality data were available.

Positions of large (>43 m) vessel trawls in the West Coast South Island fishing area during the period of the survey were provided by MAF Fisheries (now NIWA). Each day's trawls were entered into the Geographical Information System (GIS) ARC/INFO (Environmental Systems Research Institute Inc. 1991). The number of small (<43 m) vessel trawls in West Coast fishing areas were also provided by MAF Fisheries but their positions were not known as small vessels are not required to record that information.

The minimum distance between the *Tangaroa's* position at the start of each count and the position of any large vessel trawl on that day was calculated by ARC/INFO. The mean number of Westland petrels and unidentified *Procellaria* observed during counts in which no vessels were nearby was compared using two-sample Mann-Whitney tests with the mean number observed when at least one vessel was within 5, 10, 15 and 20 km respectively. If one or more small vessels had been recorded close by during a count, that was included in this analysis. The density of trawls in the hoki fishing area was fairly uniform over the period of the survey (Fig. 4), so closeness to at least one vessel generally indicated proximity to the hoki fishing fleet as a whole. If Westland petrel distribution is independent of the distribution of fishing vessels, then the mean number observed close to fishing vessels should not differ significantly from the mean number encountered away from fishing vessels.

Results

During the period of the survey 1804 trawls were set by 55 large vessels in the West Coast South Island fishing area and over the same period 326 trawls were made by 58 small vessels in areas 033, 034 and 035 (statistical areas of the New Zealand Exclusive Economic Zone) on the West Coast (Fig. 2).

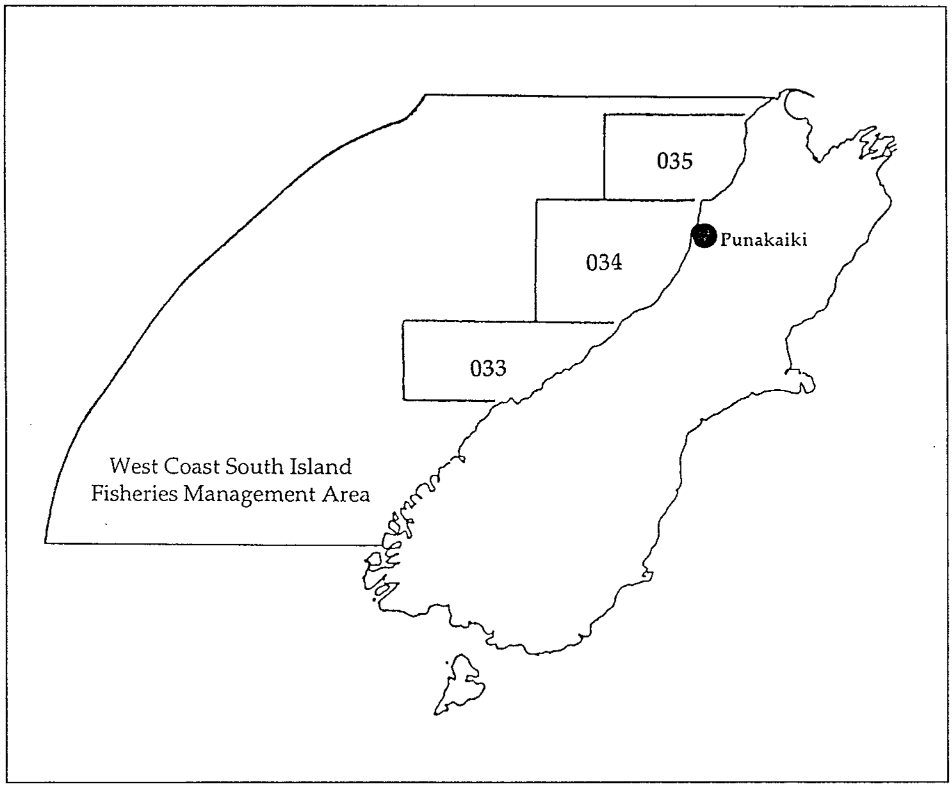

Figure 2. The West Coast South Island Fisheries Management Area and Statistical Areas 033-035 of New Zealand's Exclusive Economic Zone.

During the survey, Westland petrels and unidentified *Procellaria* were only recorded over shelf edge and inner slope waters (250-780 m). Although 10 counts were made in shallower water (100-200 m), and eight of these were near to fishing vessels, no Westland petrels or unidentified *Procellaria* were observed there. Neither were any observed during the nine counts made in deeper water (800 -1500 m). Within the 200-800 m depth range the mean number of Westland petrels nd unidentified *Procellaria* observed within 20 km of the nearest fishing vessel was significantly higher than the mean number observed further than 20 km from fishing vessels (N=124 counts, P = 0.03) (Fig.3).

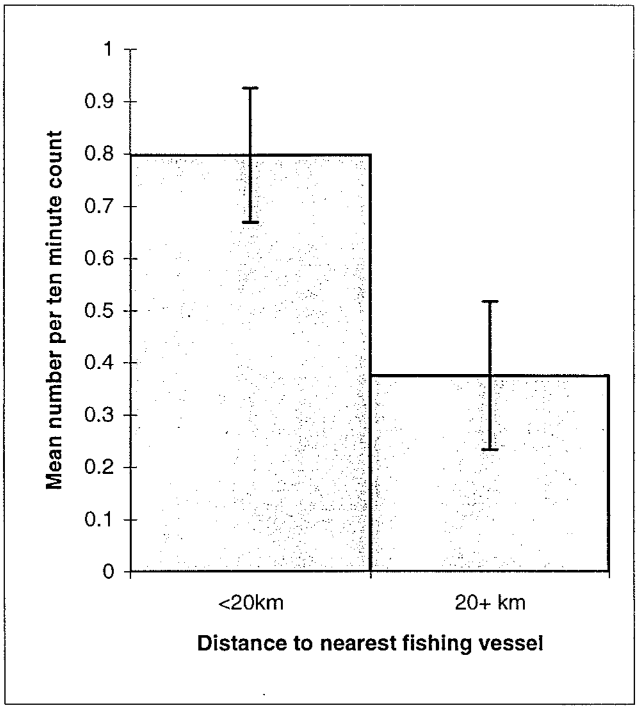

Figure 3. The mean number of *Procellaria* observed during 10 minute counts off the West Coast, South Island (means presented ± SE).

The concentration of *Procellaria* sightings in the hoki fishing area, compared to outside of the fishing area is illustrated by mapping sightings and trawl positions (Fig. 4). There were no significant differences between the numbers of Westland petrels and unidentified *Procellaria* observed within five, 10 and 15 km of fishing vessels and the numbers observed further away. Only 82 Westland petrels and unidentified *Procellaria* were recorded during the counts.

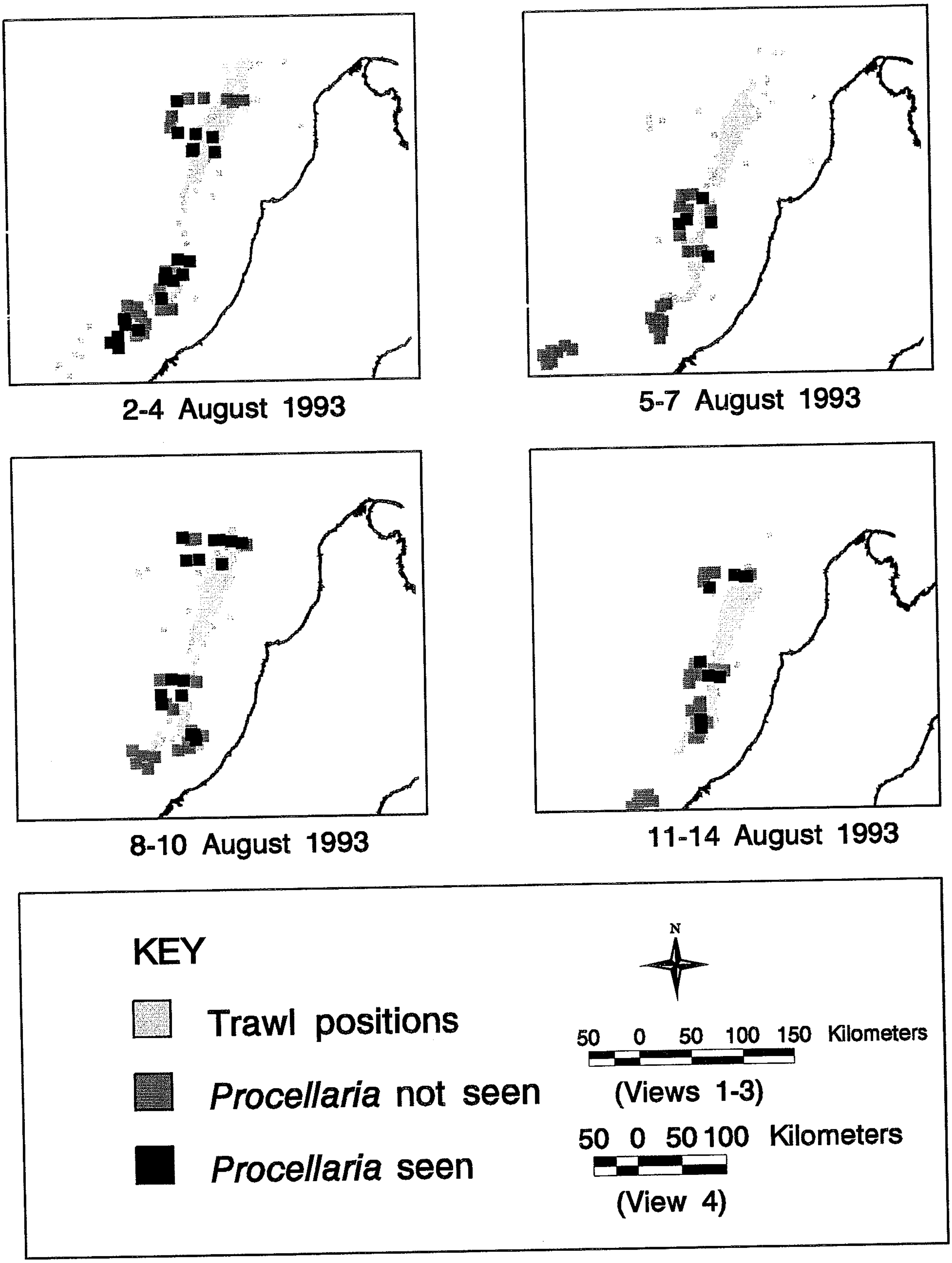

Figure 4. Distribution of large vessel trawls and *Procellaria* sightings off the West Coast of the South Island, 2-14 August 1993.

Discussion

If waste from fishing vessels is an important component of the Westland petrel's diet, the distribution of fishing vessels could be expected to influence the distribution of Westland petrels at sea. In the present study there were no significant differences between the numbers of Westland petrels and unidentified *Procellaria* observed within five, 10 and 15 km of fishing vessels and the numbers observed further away. It was not until numbers more than 20 km away from fishing vessels were considered that a significant difference was found. This is not surprising considering that the concentration of vessels in the hoki fleet could be expected to influence bird distributions over the entire fleet area as birds commute between vessels. This distance corresponds to the 15-20 km range over which Westland petrels, soaring about 5-10 m above the sea surface, could detect flocks of birds feeding behind vessels (Haney *et al.* 1992). These results indicate that vessels in the West Coast hoki fishing fleet were attracting Westland petrels, increasing their numbers within a radius of 20 km from the vessels.

Other environmental factors besides fisheries certainly influence the distribution of Westland petrels off the West Coast of the South Island. It is known that Westland petrels are continental shelf edge and inner slope feeders (Marchant & Higgins 1990) and the depth range over which Westland petrels were observed during this survey (250-780 m) is in line with this. Westland petrels were not observed near fishing vessels in shallower water (100-200 m), nor were any Westland petrels seen over deeper waters. This suggests that Westland petrels select foraging areas primarily on natural features, such as water depth, and only if fishing vessels are in the same area are Westland petrels attracted to them. However, satellite-tracking later showed (Chapter 7) that Westland petrels do, on occasion, forage close inshore and this could have been in association with inshore fishing vessels.

While Westland petrels and unidentified *Procellaria* were more numerous within 20 km of fishing vessels than further away from fishing vessels, the total number recorded was low considering the proximity of the survey to the species' breeding colony (Fig. 1).

One hypothesis was that if birds disperse randomly at sea, but aggregate around fishing vessels when they find them, then the chances of encountering birds when near to fishing vessels could be low as birds could be hidden behind vessels. However, during the survey, the *Tangaroa* passed alongside processing fishing vessels on several occasions and feeding flocks behind these vessels were closely observed, although they were not always included in the ten-minute counts. A maximum of 16 Westland petrels were seen around any one fishing vessel. Therefore it is unlikely that many birds were uncounted because they were feeding out of view behind fishing vessels.

This suggestion that the number of Westland petrels scavenging around hoki fishing vessels at any one time is low is supported by counts made from the air on 6 August 1995 when only 217 *Procellaria* were seen around the entire hoki fleet (J. A. Bartle & J-C. Stahl pers. comm.). Likewise, although up to 150 Westland petrels were observed from a vessel trawling and discharging offal on the West Coast hoki grounds in August and September 1994, numbers were generally much lower (average of 27 from eight ten-minute counts) (P. Langlands pers. comm.). The same pattern seems to occur earlier in the breeding season. For example, Langlands (1989) recorded only about five Westland petrels each time the net was hauled behind a fishing vessel off south Westland during June-July 1988. He also recorded only small numbers (maximum 11) scavenging behind a boat on the Challenger Plateau in June-July 1994 (P.Langlands pers. comm.). In contrast, Vooren (1977) saw large numbers of Westland petrels, usually about 500, aggregating at a vessel off Greymouth in October/November 1975. This could have been because more adults were feeding on waste prior to migrating.

These results show that fishing vessels do influence the distribution of Westland petrels at sea. However, at least throughout much of the breeding season, it appears that at any one time only a small proportion of the Westland petrel population is utilising the fisheries waste resource. It was not clear from this study whether only a small proportion of the population ever scavenges behind vessels, or whether a larger number are involved, but only for short periods. Other components of this research, diet studies (Chapter 3) and satellite tracking (Chapter 7), suggest that the latter scenario is more likely.

Acknowledgments

I thank Canterbury Museum, my former employer, for leave to conduct the survey; NIWA for permission to join the voyage and the crew of the *Tangaroa* for their hospitality aboard; Sira Ballara of NIWA for providing trawl data; Peter Langlands, J.A. (Sandy) Bartle and Jean-Claude Stahl for making their data available to me; Andrew Harrington, Ryan Clements and Chris Frampton of Lincoln University for GIS and statistical advise. I am also grateful to Peter Ryan, Alastair Freeman, Kerry-Jayne Wilson and an anonymous referee for their comments on earlier drafts of this paper.

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Chapter 6.

The use of satellite tracking and radio tracking methods with Westland petrels *Procellaria westlandica*

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Summary

Two foraging trips of one female and one male Westland petrel *Procellaria westlandica* partially tracked by radio telemetry, and six foraging trips by three male Westland petrels tracked by satellite telemetry are reported. We report on the development of Platform Transmitting Terminals (PTTs) suitable for use on burrowing seabirds and on the successful deployment of the modified PTTs.

The birds tracked by VHF radio telemetry were recorded around the 200 m depth contour on a few days during their foraging trip but were beyond reception range most of the time. The birds tracked by satellite mostly foraged on the continental slope off the West Coast of the South Island except in one instance where a bird flew through Cook Strait and spent time on the Chatham Rise east of the South Island. The difficulties associated with interpreting satellite tracks for birds that travel relatively short distances at sea are discussed.

General Introduction

Before 1958 the Westland petrel population was estimated to be between 3 000 - 6 000 birds (Jackson 1958). The total population (including non-breeders) is now estimated at 20 000 (Marchant & Higgins 1990). It has been suggested (Bartle 1985 1987) that this population growth was due to an increase in the food supply from offal and other waste discharged from fishing vessels, particularly in the hoki *Macruronus novaezelandiae* fishery which operates close to the Westland petrel's breeding grounds. However, little is known about the breeding season diet and foraging patterns of Westland petrels. The main aim of the radio and satellite tracking was to provide information on which fishing fleets are visited and the time spent foraging around fishing vessels compared to foraging naturally in other areas. This will be reported in subsequent papers.

Initially we attempted to determine foraging locations using VHF radio-tracking but a trial study in 1993 showed that Westland petrels forage beyond the range detectable with VHF technology. In 1995 two PTTs were used (provided by D.G. Nicholls) which were adapted for use with Westland petrels. This paper presents details of the VHF transmitter and PTT packaging, testing procedures and deployments, assessment of the effects transmitters have on Westland petrels and descriptions of the tracked flights. This paper is presented in two parts (a)VHF tracking and (b) satellite tracking.

PART A ***Tracking Westland petrels with VHF transmitters***

Introduction

In 1993 Lincoln University established VHF radio receiver stations on Paparoa Peak (831 m) near Greymouth, and Mt Rochfort (1038 m) near Westport, to investigate movements of New Zealand fur seals *Arctocephalus forsteri* (Sinclair 1994). Theoretically, the maximum distances over which VHF signals could be received by the two stations were 125 km at Mt Rochfort and 112 kms at Paparoa Peak (Sinclair 1994). This presented an opportunity to try radio-tracking Westland petrels, as their breeding colony is situated mid way between the two stations and the seal tracking coincided with the Westland petrel's breeding season. It was thought that breeding Westland petrels might forage within radio reception range.

Methods

On 8-9 July 1993, A.N.D. Freeman and J.A. Bartle with assistance from the Department of Conservation attached radio-transmitters to one female and three male Westland petrels at their breeding colony, near Punakaiki, West Coast, New Zealand. All birds were incubating eggs at the time of deployment. The transmitters were attached to the birds' backs with harnesses which had a weak link that would break if the bird became entangled (Karl & Clout 1987). The dimensions of the VHF transmitters were 60 mm x 38 mm x 10 mm. The transmitters weighed 35 g plus harness (total weight approximately 37 g), and pulsed at 80 pulses per minute with a 30 ms pulse width. As the birds weighed between 1170 and 1380 g at the time of deployment, the transmitters were 2.7-3.2% of the birds' weight. The transmitters were powered by three LTC7PN cells and could have run for 31 days on continuous transmission. However, the birds were only monitored for 10 days because the seal tracking programme ended.

Tracking was carried out between 8 July - 18 July 1993. The Westland petrels could not be tracked continuously and were generally monitored at two to four hour intervals through the night and less often during the day. Transmitters could be detected while birds were in their burrows using a portable four element Yagi antenna and receiver up to 500 m away.

The bearings of signals received at the radio-tracking stations were plotted so that triangulated positions could be determined. At both stations mountain ranges limited the area over which signals could be received. The potential area of triangulation is shown in Fig 1..

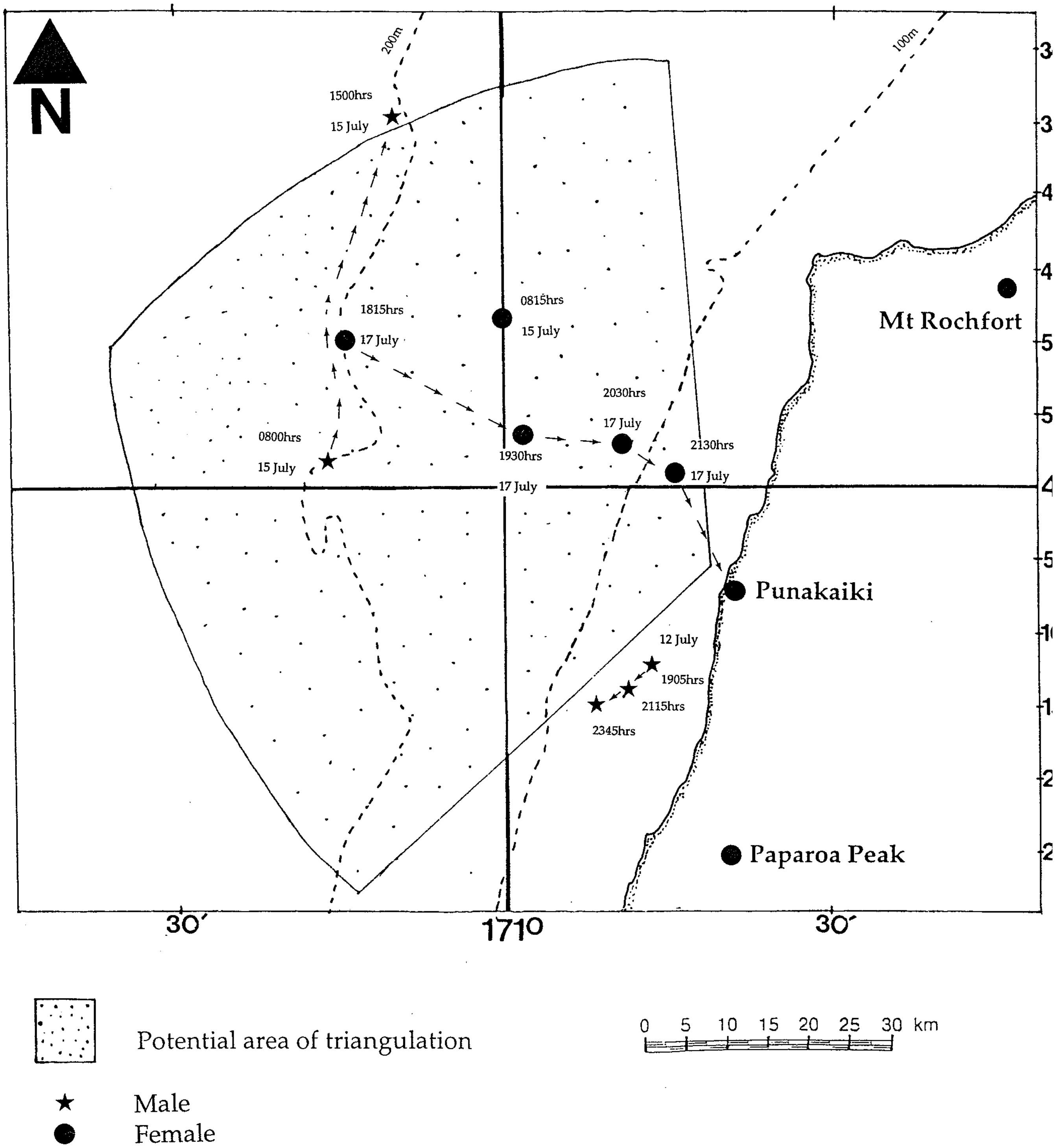

Figure 1. Locations of one male and one female Westland petrel radio-tracked in July 1993.

Results

Female (Band Nos L30187/30188)

This bird left the colony before dawn on 13 July but no signal was received from it until 0815hrs on 15 July when it was 45 km north west of the colony. By the time of the next tracking session at 1500hrs, the bird had again flown outside of radio reception range and was not located again until the evening of 17 July. During the evening of 17 July the bird was tracked from a position approximately 57 km north west of the colony to a position 24 km north west of the colony, presumably returning to its burrow (Fig. 1).

Male 1 (Band Nos L 30189/30190)

This bird left the colony before dawn on 12 July and clear signals were received at the Paparoa Peak station that evening. The strong signal at Paparoa Peak and the lack of signal at Mt Rochfort indicate that the bird was close inshore but outside the triangulation area. By 0545hrs on 13 July, the bird had flown beyond radio reception range. No signal was received at 2200hrs on 14 July but at 0800hrs on 15 July, the bird was 52 km north west of the colony. At 1500 hrs the bird had flown further north and the weak and intermittent signal indicated that it was on the edge of reception range about 100 km offshore. No further signals were received from this bird, which returned to the colony after 18 July (Fig. 1).

Male 2 (Band Nos L30183/30184)

This bird left the colony on 13 July and returned on 15 July without being detected by the radio receivers.

Male 3 (Band Nos L23066/30161)

This bird left the colony on 10 July and returned some time after 18 July when tracking had finished. It was not detected by the radio receivers.

When removing the transmitters from the birds we were concerned because the harnesses had tightened as the birds had increased in weight and girth during their foraging trips. As a result, we decided not to use harnesses in future studies of this species. Future telemetry studies of Procellariformes, which increase in girth during foraging trips, should consider this when determining the type and design of transmitter attachment.

PART B ***Tracking Westland petrels with satellite transmitters***

PTT design and testing

Since radio telemetry was found to be unsatisfactory for tracking Westland petrels, satellite telemetry was subsequently used. At 28-30 g the Microwave Telemetry Nano PTT was light enough to be carried by Westland petrels, but its standard shape (65 mm x 16 mm x 16 mm) was considered unsuitable for this species due to the height of the package (Fig. 2).

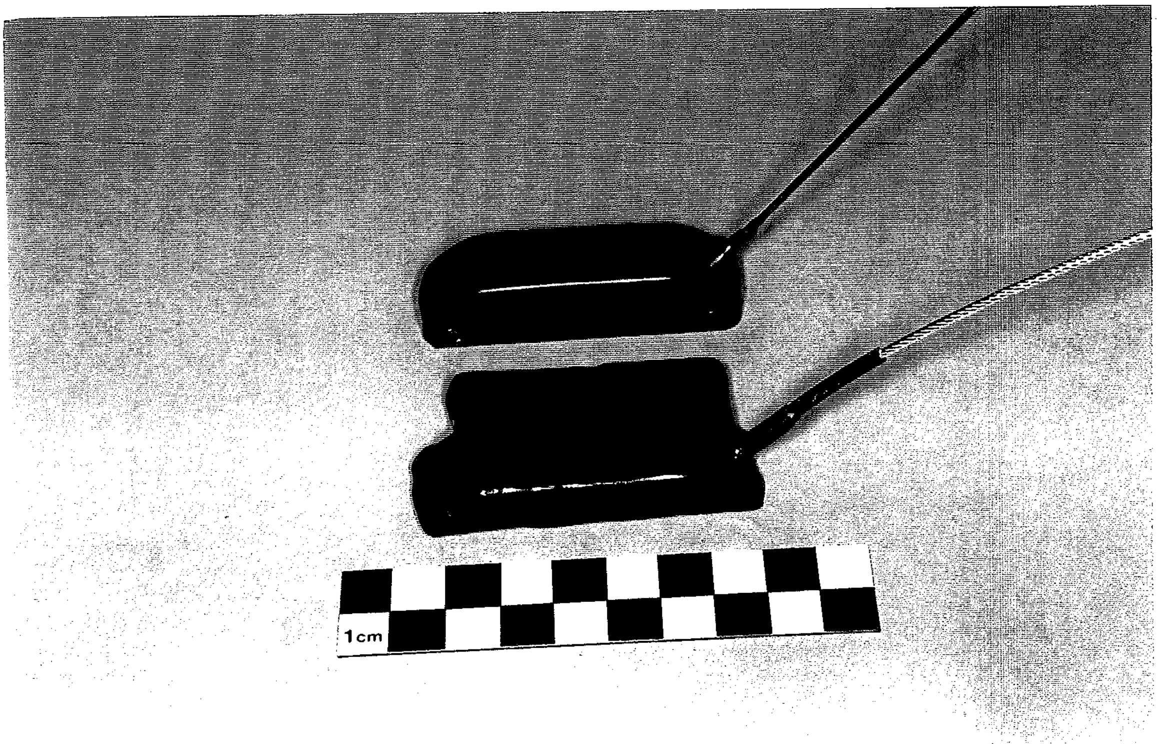

Figure 2. Standard shape Microwave Telemetry Nano PTT (above) and low profile Microwave Telemetry Nano PTT (below).

Westland petrels use burrows up to 2 m in length with entrances often only 15 - 20 cm high into which birds must squeeze. We thought it necessary to use a PTT that would not hinder birds' access to their burrows, nor be susceptible to being scraped against the tunnel roof, or entangled in exposed roots in the burrow. Similarly, the PTT attachment needed to be designed so that birds could not become entangled in trees as they crash landed through the rain-forest canopy and tangled undergrowth on their return to the colony. Consequently, we designed a package which reduced the height of the PTT by placing the battery units alongside the transmitter instead of underneath it (maximum dimensions = 65 mm x 36 mm x 10 mm) (Fig. 2). A model of the new design was measured against Westland petrel study skins in Canterbury Museum to ensure that the width was not excessive. This new design had essentially the same dimensions as the VHF transmitters deployed successfully in 1993.

In June 1995 the two designs; the standard Microwave Telemetry shaped package and the new low profile package, were tested by A.N.D. Freeman, deploying models on incubating birds. Accurately sized models of correct weight were constructed from balsa wood, lead shot and resin. The models were attached with tape to the backs of incubating birds; five flat models on 17 June 1995, and five standard shaped models on 20 June 1995. Scotch brand 471 plastic tape (12 mm width) was used for the attachment, but this tape was not sufficiently sticky and probably contributed to the loss of three of the models at sea. Four of the models were removed before the birds went to sea; either due to time constraints, or because the attachment was no longer secure.

The Westland petrel's close relative, the white chinned petrel *Procellaria aequinoctialis*, has been found to dive up to depths of 13 m (Huin 1994). We anticipated that Westland petrels would dive to similar depths. Depth gauges were attached to the top of the models to test this. The gauges were lengths of clear plastic tubing with a dusting of icing sugar inside that recorded the maximum depth attained during deployment (Huin 1994, Burger & Wilson 1988).

The results of the PTT model and maximum depth gauge deployments are shown in Table 1. The standard-shaped models proved unsuitable. Because of the height of the models, shortness of the bird's contour feathers, and rubbing against the roof of the burrow, these models soon pulled loose and pulled out feathers. Three were removed before the birds went to sea, and two birds returned from sea without the model PTTs.

The new design was more successful, with only one model lost while the bird was at sea, probably due to failure of the tape.

Table 1. Deployment and recovery of model PTTs on Westland petrels.

Model Type	*Bird Band Number*	*Sex*	*Fate of model PTT*	*Trip length (days)*	*Weight (A) (grams)*	*Weight (R) (grams)*	*Maximum Depth (m)*
Standard	L22276	F	L	5	1250		
	L16708	F	L	9-12	1150		
	L22160	F	R		1100		
	L14115	M	R		1270		
	L31715	M	R		1400		
Modified	L18650	M	S	2	1250	1300	0.7
	L14010	M	S	5	1400	1400	1.4
	L15770	M	S	11	1350	1300	7.6
	L13807	M	L	11+	1300		
	L14293	M	R		1450		

L = lost during trip; R = removed before departure; S= secure on return.
Weight (A) = weight at attachment; Weight (R) = weight on return.

The maximum depth recorded by the three recovered gauges was 7.6 m. However, errors can occur with multiple immersions (as would be the case during foraging trips) and recovered tubes showed signs of moisture accumulation, another source of error (Burger & Wilson 1988). Therefore, these results should be treated as indicative only. The real PTTs were pressure-tested to 10 metres.

The weights of the birds returning with model transmitters were close to their weights when the models were attached (Table 1). As birds did not depart immediately, they would have weighed less than shown when they left the colony. A return to their weight at the time of model attachment therefore indicates that they were able to feed successfully.

The foraging trip lengths recorded for the birds returning with model transmitters ranged from 2 to 11 days. The birds that lost their model transmitters at sea are not included as it is not known when the loss occurred. Six foraging trips of birds without model transmitters, recorded during the same time period, also ranged from two days to more than 11 days suggesting that the model transmitters did not lengthen trip duration. Of the 10 burrows in which an adult had a model transmitter fitted, nine hatched chicks (compared with overall hatching success in 1995 of 47%) so the models are not thought to have affected hatching success.

PTT deployment and satellite tracking

Methods

Three male Westland petrels with chicks were tracked by satellite between 11 August and 19 September 1995. Dates and times of attachment and recovery are given in Table 2. Initially, we intended to compare foraging trips of both older and younger males and females. However, as foraging trips were longer than expected, with only two PTTs, this was unrealistic.

Two Microwave Telemetry Nano PTTs were packaged by Sirtrack Ltd to our low profile design described above (Fig. 2). The final weights of the packages were 36.7 g and 37.9 g (2.7 and 3.7% of the birds' weight). The PTTs were encased in black epoxy polymer, the antennae reinforced with polyurethane sealant and the completed units pressure-tested to 10 m depth. The time interval between transmissions was 70 seconds, a compromise between location accuracy and battery life. One PTT pulsed continuously for the 14 days it was deployed and the other PTT pulsed continuously for 14 days and then converted to a pre-programmed reduced duty cycle of 8 hours on , 17 hours off until its batteries ran out soon after recovery - a total of 41 days.

Strips of 10mm wide "Tesa" tape as recommended by Wilson & Wilson (1989) were used for attaching the PTTs to the birds' back feathers between the wings. Two birds had no significant feather loss or damage resulting from the PTT attachment or recovery. The third had a small area of bare skin, about 1 cm^2 underneath the PTT when it was removed after 33 days. All PTTs were still firmly attached when recovered.

Table 2. Deployment and recovery details of PTTs on Westland petrels.

Bird ID/ flight	*Bird band No.*	*PTT attachment/ recovery*	*Flight start/finish*	*Trip length (days)*
Paul/1	L13807	11/8/95 1615hrs/	12/8/95 before dawn/ 16/8/95 1845hrs	5
Paul/2		24/8/95 1850hrs	17/8/95 before dawn/ 24/8/95 1850hrs	8
Sandy	L18650	11/8/95 1655hrs/ 16/8/95 0300hrs	12/8/95 before dawn/ 16/8/95 0300hrs	4
Spot/1	L22370	17/8/95 1705hrs	18/8/95 before dawn/ 31/8/95	14
Spot/2			1/9/95/ 13/9/95	13
Spot/3		19/9/95 1945hrs	15/9/95/ 19/9/95 1945hrs	5

Locations were obtained from the Argos system which records location with seven classes of accuracy: Classes 1-3, less than 1 km error; Class 0, above 1 km error; and Classes A, B and Z, accuracy not determined by Argos. The errors inherent in satellite location data for species tracked over relatively short distances presented us with problems of how to process and display these data objectively. After considering several alternatives, all classes of positions were plotted and a smoothing algorithm fitted. The smoothing algorithm plotted satellite fixes of known accuracy and substituted a weighted running average for the remaining points. The weightings used were 0.2 for classes Z, A and B; 1 for class 0 and 10 for classes 1, 2 and 3. The smoothing algorithm took into account what was known about the accuracy of the previous and next positions to objectively plot points of unknown accuracy. The equation applied to these points was:

$$\frac{(\text{prior position x weight}) + 2(\text{present position x weight}) + (\text{next position x weight})}{\text{weight}_{\text{previous}} + 2\ \text{weight}_{\text{present}} + \text{weight}_{\text{next}}}$$

The effect of the smoothing algorithm can be seen by comparing the points received from Argos with the flight paths derived from the algorithm (Figs. 3-5).

A radio receiver (model AOR 1500) was used in the later stages of tracking to detect when the last bird tracked was close to, or had returned to, the colony. Signals were received from the PTT the night before the bird returned to shore. However, as the PTT was on a reduced duty cycle and was not transmitting when the bird returned, it is not known whether or not the receiver would have detected the bird's return. After the PTT was recovered and was next transmitting it was placed in several different burrows to test whether the receiver could detect PTTs on birds in burrows from the campsite (up to 200 m away). In all cases clear signals were received.

Results

Paul (Band No L13807), an experienced breeding male first banded in 1970, left the colony on his first tracked foraging trip before dawn on 12 August 1995 and returned to the colony on the evening of 16 August 1995. During that time, Paul's locations were concentrated in two areas 90 km north-west and 80 km west of the colony; 41°30'S, 170°40'E and 42°10'S, 170°20'E on the continental slope. Paul was tracked for a second flight on which he departed before dawn on 17 August 1995 and returned on the evening of 24 August 1995. On Paul's second trip, he travelled south-west and locations were concentrated 150 km south-west of the colony at 42°30'S, 170°10'E and as far as 300 km south-west at 43°40'S, 169°10'E also on the continental slope (Fig. 3).

Sandy (Band No L 18650), a 17yr old male that had bred only once since 1991, left the colony before dawn on 12 August 1995 and returned at 3am on 16 August. During his foraging trip, locations were concentrated at 42°20'S, 170°20'E but also covered areas south west and west of the colony between approximately 41°40'S and 43°S and 169°20'E and 171°E. Most positions were on the continental slope (Fig. 4).

Spot (Band No L 22370), a male of unknown age, left the colony before dawn on 18 August 1995 and was not recaptured until 19 September 1995. However, because his burrow was not monitored constantly over that period, there are two occasions when the satellite data suggests he returned to his burrow; 31 August 1995 and 13-15 September 1995. The period 18 August - 19 September is therefore assumed to cover three foraging trips; 18-31 August, 1-13 September and 15-19 September.

Spot spent the first two days of his first foraging trip north-west of the colony. Locations received were concentrated in the area 41°30'S, 170°30' E. Spot then flew rapidly through Cook Strait on 20 August and spent until 25 August in Cook Strait and on the eastern edge of the Chatham Rise. His homeward flight took him back through Cook Strait on 26 August and by 27 August he was close inshore in the Karamea Bight. He then returned to the area in which he had spent the first two days of his trip and from there he is presumed to have returned to the colony for not more than two hours on 31 August. Two hours was the maximum time between checks of Spot's burrow on that night.

On Spot's second foraging trip he flew in large circles west of the colony on the continental slope. He is presumed to have spent the nights of 13 and 14 September ashore, departing again on 15 September. He visited the same area of the continental slope during his third foraging trip and returned to the colony on the evening of 19 September (Fig. 5).

All three birds increased in weight between PTT attachment and recovery indicating that they fed successfully during their foraging trips (Table 2). Their foraging trips ranged in length from four to fourteen days and were comparable with the highly variable trip lengths recorded for untracked birds in other burrows. Eighteen foraging trips by other male and female Westland petrels monitored during August and September 1995 ranged in length from 1day to at least 9 days (2 birds had been absent for 9 days when monitoring stopped). All three satellite-tracked birds had chicks approaching fledging when their burrows were inspected on 15 November 1995.

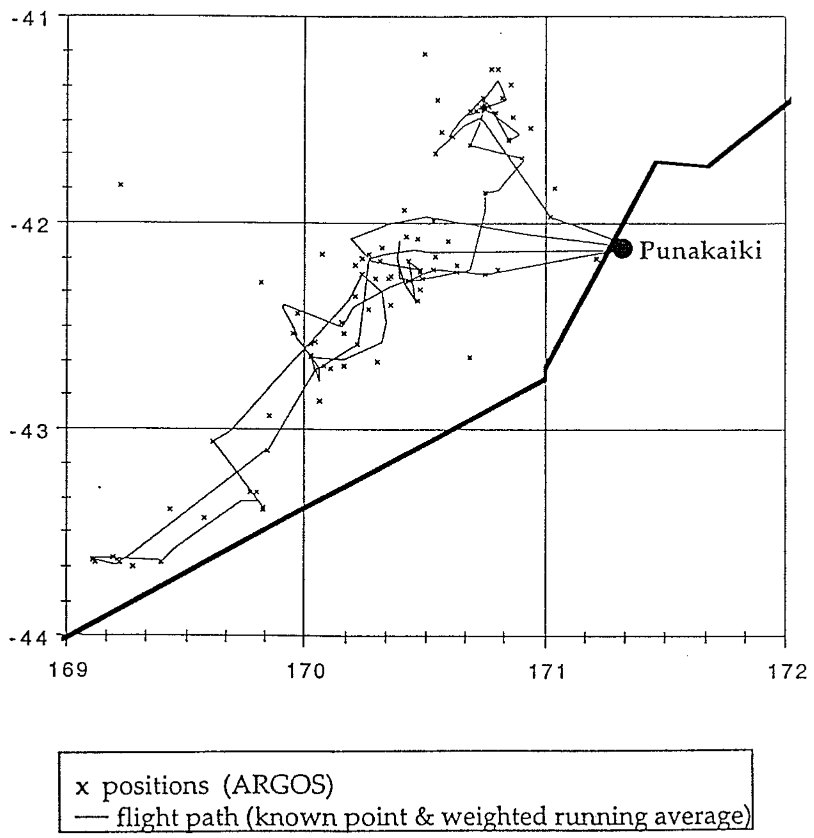

Figure 3. Satellite tracks of Paul 12 - 16 August 1995.

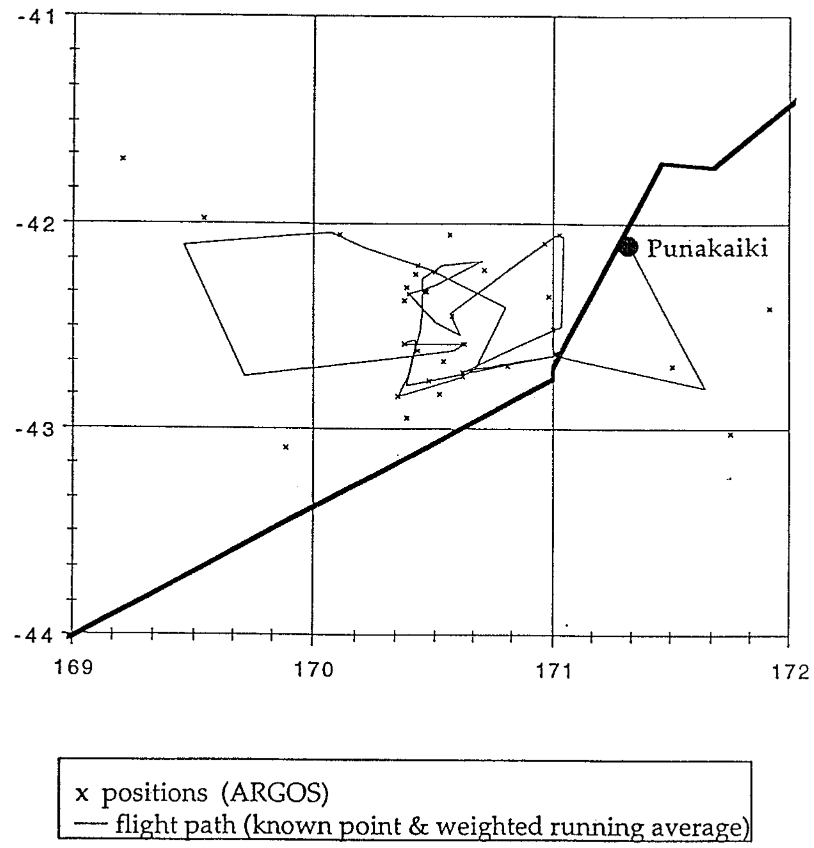

Figure 4. Satellite track of Sandy 12 - 16 August 1995.

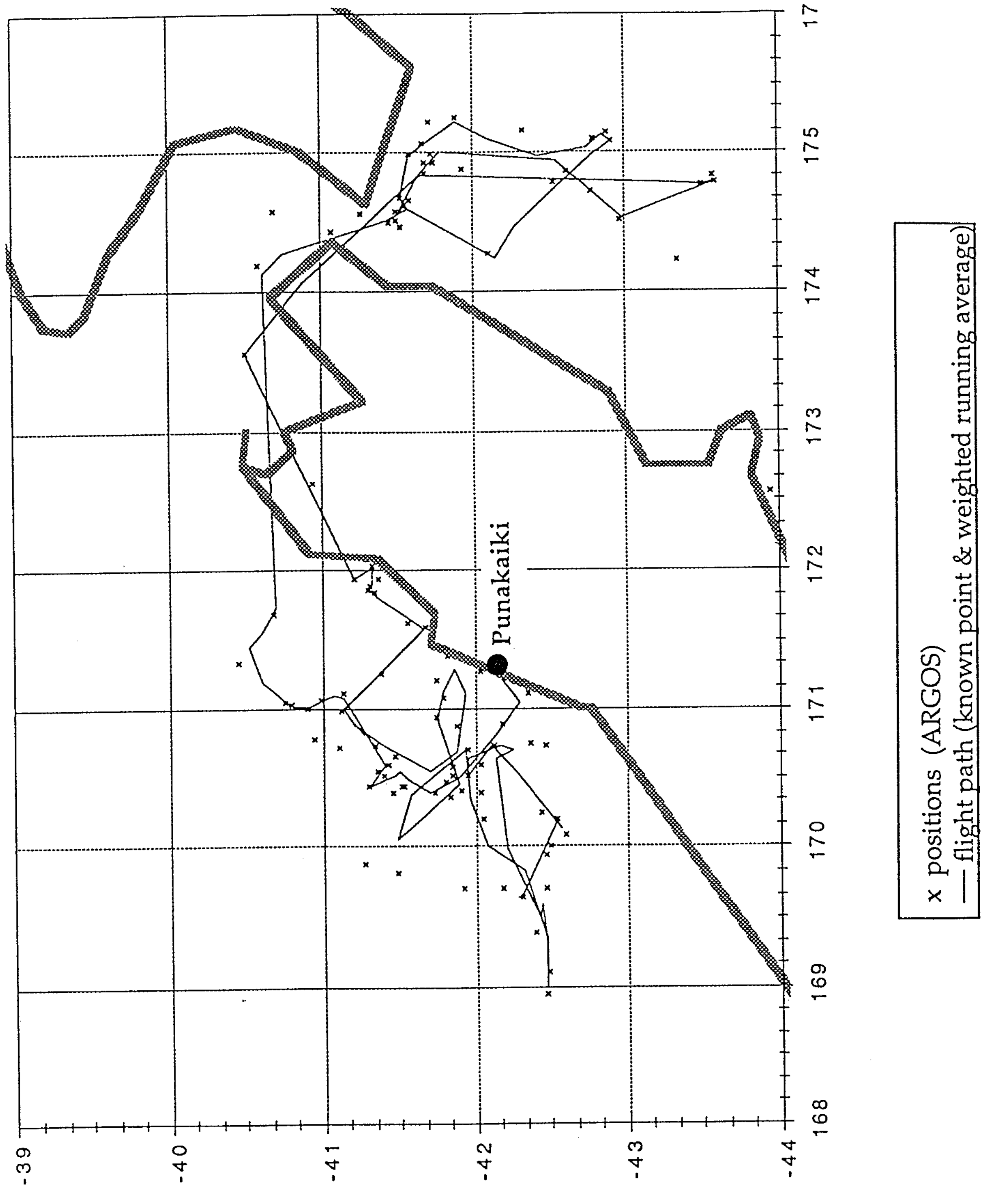

Figure 5. Satellite tracks of Spot 18 August - 19 September 1995.

Discussion

Both of the birds tracked by VHF radio telemetry were recorded around the 200 m depth contour on a few days during their foraging trip but were beyond reception range most of the time. From what is known of Westland petrel distribution at sea, and has now been shown by satellite tracking, it is possible that birds were feeding on the continental slope, outside of radio reception range, during the times that signals were not received.

Although the theoretical range of the radio tracking equipment was about 100 km, it is possible that factors such as weather conditions and interference reduced signal quality and the distance over which signals could be received (Sinclair 1994). At short distances, however, signals were strong (A.B. Freeman pers. comm.), and as all transmitters were still functioning when recovered, we are confident that signals could be received whenever the birds were within range. The distances over which Westland petrels forage during incubation made VHF radio telemetry unsatisfactory for tracking them.

The satellite-tracked flights reported here are some of the first recorded for a petrel smaller than an albatross, mollymawk or giant petrel. The results confirm the impression, gained during radio-tracking, of the importance of the continental slope to breeding Westland petrels. They also show that a breeding bird can complete a long distance flight ranging as far as 800 km from the colony.

Experiments with model PTTs showed that a low profile PTT package is necessary for burrowing birds to prevent damage from the burrow roof and to provide an adequate attachment for birds with short contour feathers. Attaching the PTTs with tape provided a secure attachment that was quick and easy to apply and remove. Tape is considered preferable to the harnesses which became tight at the end of foraging trips and had the risk of snagging in vegetation.

The majority of positions received from ARGOS for birds in this study were of unknown accuracy. Over the relatively short distances breeding Westland petrels fly, location errors are likely to be significant and will limit our ability to relate locations to fishing activity, one of the objectives of this study that will be reported in a subsequent paper. These inaccuracies also mean that estimates of distance and direction between successive points are dubious; and the number of known-accuracy points were too few to calculate flight speed. Applying an algorithm that uses what is known about the accuracy of previous and next positions to plot points of unknown accuracy provides an objective way to smooth and interpret the flight paths.

Delays of several hours often occur between satellite fixes and the data becoming available. For our Westland petrel tracking this meant that we had to maintain a watch over birds' burrows each night in order to be sure of recapturing birds as the satellite data was not current enough to give early warning of a bird's return. Maintaining a constant watch was not feasible due to weather conditions and time constraints and so we appear to have missed two of Spot's returns to the colony. Use of a hand-held AOR 1500 receiver on the colony can alleviate this problem by making detection possible from a campsite.

Our study has shown that satellite tracking can provide useful data on general foraging areas and patterns of a procellariid seabird which was not achievable using VHF radio tracking.

Acknowledgments

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Chapter 7.

Westland petrels and the hoki fishery: determining co-occurrence using satellite telemetry

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Summary

Project

Westland petrels were tracked by satellite and the tracks followed by the birds compared to the distribution of hoki fishing vessels. The proportion of time that Westland petrels spent in the vicinity of fishing vessels is used to assess the potential contribution of fisheries waste to the Westland petrel diet.

Objective

To determine the proportion of time that Westland petrels spend in the vicinity of hoki fishing vessels.

Methods

- Twelve Westland petrels were tracked by satellite for a total of 22 foraging trips.

- Positions of vessels in the West Coast South Island and Cook Strait fishing areas during the periods of satellite tracking were plotted in the Geographical Information System ArcView®.

- The birds' foraging trips were compared with the distribution of fishing vessels and the proportion of time that they spent in the vicinity of fishing vessels was assessed.

Results

- Most birds that were tracked foraged over the continental shelf and slope west of the Westland petrel colony. However, two birds travelled through Cook Strait, and three birds spent considerable time inshore during their foraging trips.

- There was considerable variation in the amount of time that Westland petrels spent in the vicinity of hoki fishing vessels. Some birds spent as much as half their foraging trip near the fishing fleet, while some birds spent very little time near vessels.

Conclusion

Satellite tracked Westland petrels spent ample time in areas where fisheries waste could make an important contribution to their diet. Their reduced flight speed while near vessels indicates that they were scavenging there. The tracked birds did, however, forage over much wider areas than those occupied by the hoki fishing fleets.

Introduction

Westland petrels *Procellaria westlandica* breed only near Punakaiki on the West Coast of New Zealand. About 80 km off shore from their colony, New Zealand's largest commercial fishery, for hoki *Macruronus novaezelandiae* operates from mid June to early September. This period coincides with the Westland petrel's breeding season. Waste from the hoki fishery represents a large potential food source for Westland petrels and other seabirds. Currently, in the main hoki fishing areas, around 100 000 t is caught off the West Coast, and a further 40 000 t in the Cook Strait each year and tens of thousands of tonnes of offal and discarded fish are discharged as waste.

The use of fisheries waste by scavenging seabirds has received increasing attention in recent years and several studies have found waste to be an important component in the diet of species which have learnt to exploit this abundant and readily available food source. For example, Jackson (1988) found that trawl offal was the dominant food by mass of the white-chinned petrel *Procellaria aequinoctialis* in the southern Benguela region. This interest in scavenging on fisheries waste arises from the concern expressed by some seabird biologists that if a large enough proportion of a species' population comes to depend on scavenging waste at fishing vessels, they could experience a food crisis if fishing operations altered or ceased (eg Bartle 1974, Abrams 1983).

Apparently, in the late 1950s, few Westland petrels fed on trawl waste from fishing vessels, but the number feeding on the Cook Strait trawling grounds greatly increased during the 1960s (Bartle 1974). With the development of the hoki fishery in the 1970s, Westland petrels were observed feeding on fisheries waste during exploratory fishing off Greymouth (Vooren 1977). In recent years, Westland petrels have regularly been recorded scavenging behind West Coast hoki trawlers (P. Langlands pers. comm.; A.N.D. Freeman pers. obs.). Given the size of the fishery, its proximity to the Westland petrel's breeding area, and the timing of the hoki fishing season, we considered the West Coast hoki fishery likely to be the Westland petrel's most utilised source of fisheries waste.

It has been assumed that Westland petrels feed extensively on fisheries waste and this habit has been considered at least partly responsible for an increase in the Westland petrel population (Bartle 1985 and 1987). Feeding on fisheries waste has also been implicated in malnutrition, resulting in the feather malformation present in 20-30% of Westland petrel fledglings (J.A. Bartle unpublished data). However, until now, there have been no studies to test the assertion that fisheries waste is an important food source for Westland petrels.

The main aim of this satellite tracking programme was to determine the proportion of time that Westland petrels spend in the vicinity of hoki fishing vessels. This was achieved by comparing the birds' mapped foraging trips to the distribution of hoki vessels, and calculating the proportion of time that birds spent in proximity to the hoki fleet compared to time spent foraging elsewhere. This satellite tracking programme was complemented by diet studies and a survey of Westland petrels at sea in a wider study of the importance of fisheries waste in the diet of Westland petrels.

Methods

Breeding season energy requirements are greatest during chick guarding, a period after hatching when one or other parent stays in the burrow to guard the chick (Ricklefs 1983). Scavenging on fisheries waste could be expected to be most prevalent during that time. However, very young petrel chicks suffer high mortality (Warham 1996) and we were concerned about the possibility of increasing the chances of desertion if tracking was carried out immediately after hatching. Our satellite tracking period was therefore a compromise timed to cover the end of the guard stage and the start of the period when chicks are left on their own in the burrow. Between 11 August and 19 September 1995, three male Westland petrels were tracked by satellite for a total of six foraging trips. The details of their PTTs (Platform Transmitting Terminals) and PTT attachment and recovery are given in Chapter 6. Between 6 August and 3 September 1996, 4 female and 5 male Westland petrels were satellite tracked for a total of 16 foraging trips. Seven of these birds were tracked for two trips, two were tracked for one trip only. Because male Westland petrels spend more time ashore (J.A. Bartle pers. comm., A.N.D. Freeman pers. obs.), it was easier to find males to attach PTTs to and hence we tracked fewer females than males. The dates and times of attachment and recovery of PTTs in 1996 are shown in Table 1.

Table 1. 1996 PTT deployment and recovery details.

Bird ID sex/ flight	*Band No.*	*PTT attachment /recovery weight (g)*	*Flight start/finish*	*Trip (days)*
Merlene F/1	L31707	5/8/96 1600hrs 1180g	6/8/96 before dawn/ 8/8/96 2115hrs	3
Merlene F/2		13/8/96 1930hrs 1280g	11/8/96 before dawn/ 13/8/96 1930hrs	3
Kevin M/1	L13961	5/8/96 1730hrs 1200g	6/8/96 before dawn/ 6/8/96 2300hrs	1
Kevin M/2		10/8/96 2300hrs 1350g	7/8/96 before dawn/ 10/8/96 2300hrs	4
Toni F/1	L31706	5/8/96 1800hrs 1000g	6/8/96 before dawn/ 13/8/96 0045hrs	7
Toni F/2		16/8/96 0130hrs 1150g	13/8/96 before dawn/ 16/8/96 0130hrs	3
Ann F/1	L14239	10/8/96 2330hrs 1150g	13/8/96 before dawn/ 14/8/96 before dawn	1
Ann F/2		22/8/96 2130hrs 1300g	16/8/96 before dawn/ 22/8/96 2130hrs	7
Andrew M/1	L14293	14/8/96 1800hrs 1150g	16/8/96 before dawn/ 16/8/96 2300hrs	1
Andrew M/2		21/8/96 0700hrs 1300g	18/8/96 before dawn/ 21/8/96 before dawn	3
Danyon M/1	L19575	16/8/96 1800hrs 1150g	18/8/96 1930hrs/ 22/8/96 2300hrs	4
Danyon M/2		25/8/96 1900hrs 1150g	23/8/96 before dawn/ 25/8/96 1900hrs	3
Dot F/1	L22269	23/8/96 1915hrs 1200g	24/8/96 before dawn/ 26/8/96 2000hrs	3
Dot F/2		3/9/96 1930hrs 1150g	27/8/96 before dawn/ 3/9/96 1930hrs	8
Blythe M	L14010	22/8/96 1630hrs 1400g 29/8/96 0145hrs 1400g	24/8/96 before dawn/ 29/8/96 0145hrs	5
Ready Teddy M	L15731	25/8/96 2015hrs 1200g 1/9/96 2215hrs 1250g	29/8/96 before dawn/ 1/9/96 2215hrs	4

Three Microwave Telemetry Pico PTTs were deployed on Westland petrels in 1996. The low profile packages designed by us (Chapter 6) were constructed by Sirtrack Limited. The final weight of the packages was 37 g (approximately 3% of the birds' weight). The time interval between transmissions was 75 - 77 seconds; a compromise between location accuracy and battery life. The PTTs transmitted continuously and had a battery life of approximately 33 days (800 hours).

Tesa brand adhesive tape, as recommended by Wilson & Wilson (1989), was used for attaching the PTTs to the bird's back feathers between the wings (Fig. 1). No birds had any significant feather loss or damage resulting from the PTT attachment or recovery. All PTTs were still firmly attached when recovered. Birds were weighed when the PTTs were attached and again when the PTTs were removed.

Figure 1. Satellite transmitter (PTT) being deployed on a Westland petrel, showing the Tesa tape attachment (photo A.B. Freeman).

In 1996, two alarm systems were installed to detect when satellite tracked birds returned to the colony. These proved invaluable in reducing damage to the ground cover from frequent burrow checking, and enabled us to shelter and rest while waiting.

One alarm was fitted by Sirtrack Limited to an AR 1500 receiver (AOR Pty Ltd, Japan). The unit detected any PTT signal emitted close to the colony. It was not clear at what distance this alarm could detect PTTs, but limited testing by us indicated that it was at least 1-2 km and probably more on the study site where signal interference was minimal. On detecting a PTT, a loud alarm would sound alerting us to the arrival of a bird. The advantage of this alarm was that it could monitor any number of PTTs. The disadvantage was that if a bird with a PTT was already on the colony the alarm would trigger continuously and could not therefore be set to detect the arrival of further birds.

The second alarm was designed and built by Lincoln University instrument technicians. This alarm was linked to an infra red sensor on a long cable. The sensor was installed at the burrow of a bird with a PTT when we wished to catch it, and when a bird entered the burrow, the alarm was triggered in the tent (Fig. 2).

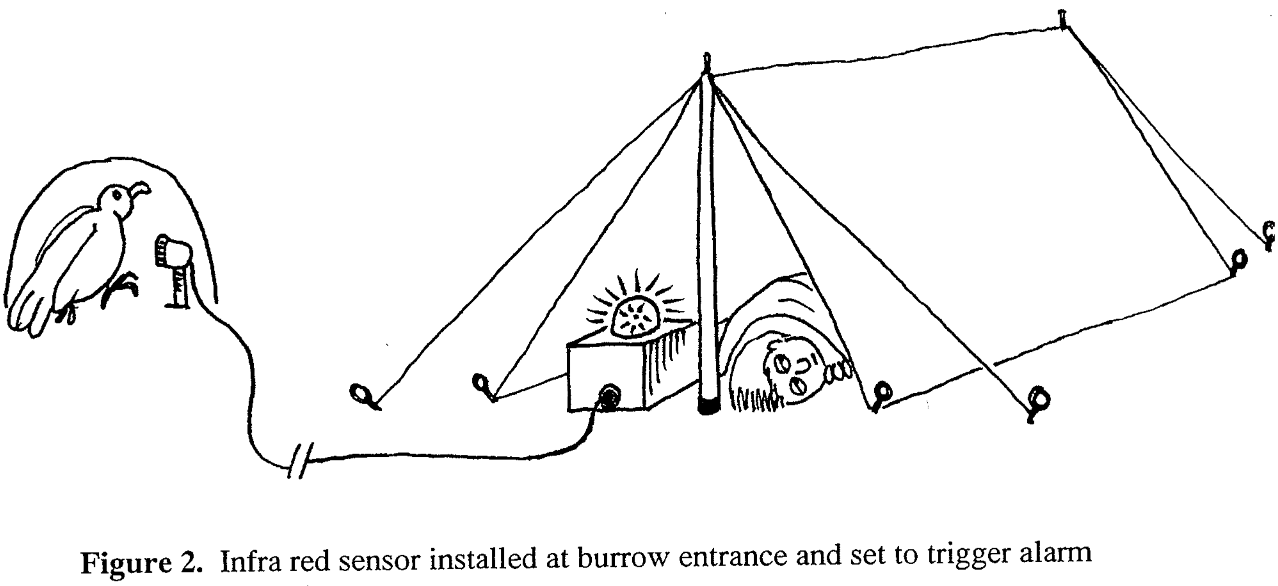

Figure 2. Infra red sensor installed at burrow entrance and set to trigger alarm (diagram C. Vink).

The advantage of this alarm was that it could be operated regardless of other birds fitted with PTTs being in the area, and triggered only when a bird had actually returned to its burrow. The disadvantage was that only one burrow could be monitored, and not only the tracked bird, but also its partner and any other passing birds would trigger the alarm. By operating both of these alarms in tandem, the arrival of nearly all tracked birds was closely monitored.

Birds' locations were obtained from the Argos satellite tracking system which records location with seven classes of accuracy: Classes 1-3, less than 1 km error; Class 0, above 1 km error; and Classes A, B and Z, accuracy not determined by Argos. Thirteen percent of the records we received were in Classes 1-3, 52% in Class 0 and 35% in Classes A, B, and Z. We received an average of eight satellite fixes per day for each PTT. In 1995, a smoothing algorithm was fitted to the positions reported by Argos in an attempt to account for differences in the accuracy of points (Chapter 6.). The smoothed flights for 1995 are displayed here and used in analysis. However, as application of the smoothing algorithm made little difference to the mapped flights (see Chapter 6. Figs. 3-5), and added another layer of interpretation to our results, it was not used in 1996. The raw data is presented for the 1996 flights apart from Z class locations which were excluded from the analysis because of their obvious inaccuracy (eg distance between points implying impossible flight speeds and inland locations).

Positions of vessels in the WCSI (West Coast South Island) and Cook Strait fishing areas during the periods of satellite tracking were provided by NIWA[1]. The data provided is taken from vessels' TCEPR[2] forms on which all vessels larger than 43m are required to record the positions of their trawls. As vessels in the hoki fishery typically do not move very far, and generally process their previous catch while trawling, their position at the start of each tow provides a reasonable approximation for the positions where waste is discharged (pers. obs.).

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1 National Institute of Water and Atmospheric Research
2 Trawl and catch effort processing return

The great majority of vessels in the West Coast hoki fishery are obliged to complete TCEPRs and it is estimated that 97% of the total catch in the WCSI fishing area is recorded on TCEPRs (S. Ballara pers. comm.). In the Cook Strait hoki fishery the situation is more complicated. Only vessels less than 43 m may fish in Cook Strait and these vessels are not obliged to complete TCEPRs although many do (c. 88% of total catch recorded on TCEPRs) (S. Ballara pers. comm.). The remainder complete CELR[3] forms which are unlikely to have trawl positions recorded. The data for Cook Strait is therefore a less complete record of trawl positions.

For each day that Westland petrels were tracked, the position of all reported trawls from the TCEPRs were entered into the Geographical Information System ArcView® (Environmental Systems Research Institute Inc, 1994). The positions of birds were also entered into ArcView® and routes of the birds' foraging trips mapped. Distances between the birds' positions and the nearest hoki fishing vessel(s) were measured in ArcView®.

Petrels typically fly over vast areas of ocean without alighting except when food is sighted (Warham 1996). We might therefore find clues to a bird's activity, for example, whether it is searching for food or feeding, by examining the speeds at which birds travel during satellite tracked foraging trips. For example Walker *et al.* (1995) found differences in apparent flight speeds of wandering albatross *Diomedea exulans* at different stages of their foraging trips depending on whether they were commuting or foraging; a pattern similar to that observed for light-mantled sooty albatross *Phoebetria palpebrata* (Weimerskirch & Robertson 1994).

If Westland petrels were actively scavenging around fishing vessels, we might expect to find that their average flight speeds would be lower in the hoki fishing areas than outside, because they would be spending more time on the water. To calculate the flight speeds of birds when they were in the vicinity of fishing vessels and when they were at some distance from the hoki fishing fleet, we measured the distance between pairs of

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[3] Catch effort landing return

satellite locations in ArcView®, and categorised them as either "close to" or "distant from" vessels.

We were concerned that the additional weight of the PTTs could alter the duration of the birds' foraging trips; perhaps lengthening them as the birds had to work harder travelling to food sources, or were less adept at catching prey. Therefore, the lengths of foraging trips of satellite tracked birds were compared with trips made by birds not carrying PTTs. The foraging trips of non-tracked birds were determined by direct observation of burrows, and by using automatic cameras installed at burrow entrances.

In 1995 and 1996, three Trailmaster® (TM 1500) automatic camera and event recording systems were installed at a total of eight burrows (Fig. 3). As a bird entered a burrow where a Trailmaster® was installed, it broke an infra red beam which triggered a camera positioned nearby. Birds in these burrows were marked with white enamel paint to allow males and females to be told apart in the resulting photographs (Fig. 4).

Figure 3. Trailmaster® camera (top right) and event recorder (bottom left) at a Westland petrel burrow (photo A.B. Freeman).

Figure 4. Photograph taken by Trailmaster® camera of a male Westland petrel (marked on head and wings with white paint) leaving his burrow.

Recent studies that have examined satellite tracks in relation to the duration of foraging trips have found that foraging trip lengths reflect species' foraging strategies. For example, results obtained by Weimerskirch *et al.* (1993) on the movements of wandering albatross suggest that during short trips birds forage over the shelf areas and neighbouring waters, whereas on long trips, they forage extensively over pelagic waters. This pattern could be widespread among petrels; Weimerskirch *et al.* (1994a) found another four species which either alternated or mixed long and short foraging trips, storing energy to maintain adult condition during the long trips and delivering more food to their chick after short trips. The frequency distribution of their foraging trips was bimodal, with trips falling into distinct long and short categories. Significantly, two species in that study did not display this dual strategy. Black-browed albatrosses *Diomedea melanophrys* and common diving petrels *Pelecanoides urinatrix*, both birds apparently restricted to the shelf during the breeding season, displayed a unimodal frequency distribution of foraging trip lengths unlike the bimodal pattern observed in the other, pelagic, species. We used satellite tracks to examine the relationship between proximity to fishing vessels and foraging trip length in Westland petrels and to assess the potential contribution of fisheries waste to adult maintenance and chick provisioning.

To provide a control for the affects of handling, groups of control burrows with chicks, 11 in 1995 and 10 in 1996, were selected. Adults from these burrows were not satellite tracked, or used in the diet sampling and foraging trip studies which were also conducted.

Faced with increased energetic demands, adult petrels should maintain their own nutritional condition at the expense of their chick (Mauck & Grubb 1995). We could therefore expect any detrimental effects of satellite tracking to be reflected in the condition of chicks. Just prior to fledging, in November 1995 and 1996, chicks of satellite tracked adults and chicks in control burrows had their wing lengths measured (flattened wing chord) and were weighed with a Pesola spring balance.

Results

Descriptions of the birds' flights

The flights are illustrated in the accompanying maps (Figs. 5 - 12). Where low accuracy satellite fixes gave improbable inland positions for birds these are shown on the maps but are excluded from the flight paths. The 1995 maps are of the smoothed flights, and the 1996 maps do not include Z class locations (see p94). Where a diet sample was collected from a bird returning from a tracked foraging trip, the contents of that sample are described. Samples were only collected from birds returning from their last tracked flight.

Paul

On Paul's first tracked flight (12/8/95 - 16/8/95), he spent time c. 60 km west of the colony and c. 100 km north west of the colony, mainly along the 200 m depth contour and in the vicinity of the WCSI hoki fishery. On his second tracked flight (17/8/95 -

24/8/95) he travelled up to 300 km south west of the colony, again mainly following the 200 m depth contour, and spent less time near the WCSI fishing fleet (Fig. 5).

Sandy

Sandy remained relatively close to shore on his tracked flight (12/8/95 - 16/8/95); inside the 200 m depth contour and within 60 - 80 km west and south west of the colony. He spent little time in the vicinity of the WCSI hoki fishery; however the diet sample taken from Sandy on his return to the colony was comprised solely of fish, identified as hoki by electrophoresis (Chapter 4.) (Fig. 5).

Spot

On Spot's first tracked flight (18/8/95 - 31/8/95) he moved along the 200 m depth contour, just west of the WCSI hoki fleet then flew directly to Cook Strait. He then travelled south to near Banks Peninsula where he was in the vicinity of fishing vessels. On his return to the colony he passed through the WCSI hoki fleet. Spot's second tracked flight (1/9/95 - 13/9/95) was 80 - 150km west of the colony and mainly beyond the WCSI hoki fleet. His third flight (14/9/95 - 19/9/95) consisted of a loop from north west to south west of the colony, out beyond the 200 m depth contour and west of the WCSI hoki fleet, c. 130 km off shore (Fig. 6).

Toni

On Toni's first tracked flight (6/8/96 - 12/8/96) she travelled close to shore around Cape Farewell to Cook Strait but spent little time in the vicinity of the Cook Strait hoki fleet. She returned to the colony close to land and did not visit the WCSI fishing fleet. Toni's second flight (13/8/96 - 16/8/96) was also mostly close inshore. She kept within 20km of the shore as she travelled up to 150 km north of the colony. On her return, she made a brief visit to the WCSI hoki fishing area 50 - 80 km west of the colony (Fig. 7).

Blythe

Blythe's tracked flight (24/8/96 - 29/8/96) was along the 200 m depth contour on the western edge of the WCSI hoki fishing area, 80 km west of the colony, and further south west 180 km from the colony (Fig. 7). The diet sample collected from Blythe on his return was comprised entirely of fish. It could not be matched with any common species found in fisheries waste.

Merlene

Merlene's first tracked flight (6/8/96 - 8/8/96) was mostly west of the WCSI hoki fishery and the 200 m depth contour, c.150km west of the colony. Her second flight (11/8/96 - 13/8/96) was mainly in the WCSI hoki fishing area, close to the 200 m depth contour, 80 - 100 km north west of the colony (Fig. 8). The diet sample collected from Merlene after her second tracked flight was comprised entirely of heavily digested fish which could not be identified.

Andrew

On Andrew's first tracked flight which lasted just one day (16/8/96) he was c.80 km west of the colony reaching as far offshore as the WCSI fishing fleet. His second flight (18/8/96 - 21/8/96) was mostly along the 200 m depth contour amongst the WCSI hoki fishing fleet, c.80 km west and north west of the colony (Fig. 9).

Danyon

On Danyon's first tracked flight (18/8/96 - 22/8/96) he was c.130-170 km west of the colony, beyond the 200 m depth contour and the WCSI hoki fishing fleet. His second tracked flight (23/8/96 - 25/8/96) was also beyond the WCSI fleet and 200 m contour, c. 80 - 100 km west of the colony (Fig. 10).

Kevin

Kevin's first tracked flight of one day (6/8/96) was spent mostly in the vicinity of the WCSI hoki fishing fleet, 80 - 90 km west of the colony. On his second flight (7/8/96 - 10/8/96) he moved in and out of the WCSI hoki fishing area, with most time spent 80 - 90 km south west of the colony (Fig. 10).

Ann

Ann's first tracked flight (13/8/96 - 14/8/96) took her 80 km west of the colony, out to the WCSI hoki fishing area and back. Her second flight (16/8/96 - 22/8/96) was mostly along the western edge of the WCSI hoki fishing fleet, beyond the 200 m depth contour, c. 90 - 200 km west of the colony (Fig. 11). The diet sample collected from Ann after her second tracked flight was comprised of 90% squid and 10% fish.

Dot

On her first tracked flight (24/8/96 - 26/8/96), Dot travelled beyond the WCSI hoki fishing fleet and 200m contour, to 80 - 140 km west of the colony. Her second tracked flight (27/8/96 - 3/9/96) was mostly in the vicinity of hoki trawlers, around the 200 m depth contour (Fig. 11). Dot's diet sample, collected after her second tracked flight contained only moderately digested fish which could not be identified.

Ready Teddy

Ready Teddy's flight (29/8/96 - 1/9/96) was mainly inshore, only 20 - 30 kms from land. He spent some time c. 100 km north west of the colony on the edge of the WCSI hoki fishing fleet (Fig. 12). The diet sample collected after this trip was comprised entirely of heavily digested fish which could not be identified.

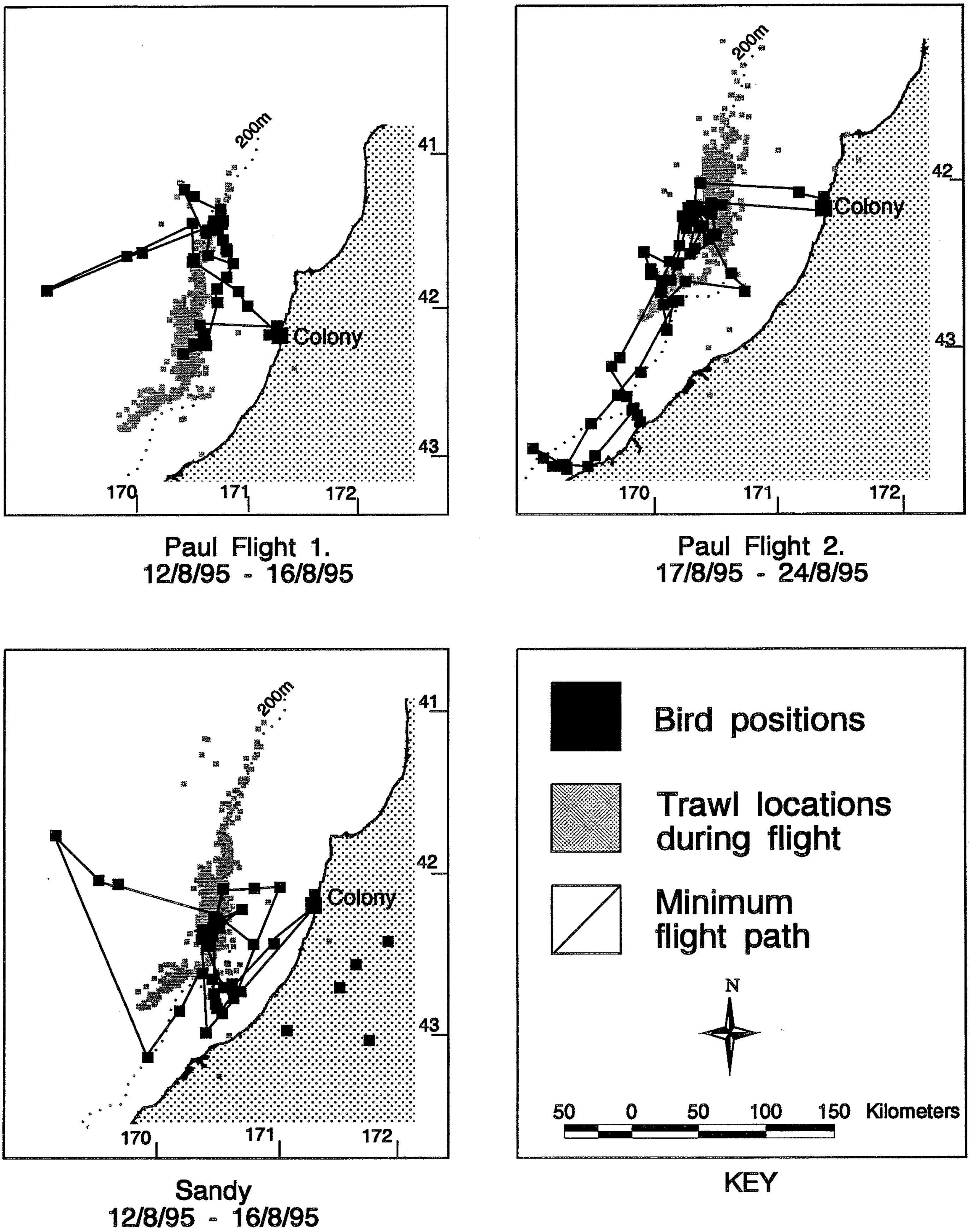

Figure 5. Satellite tracks of Paul and Sandy.

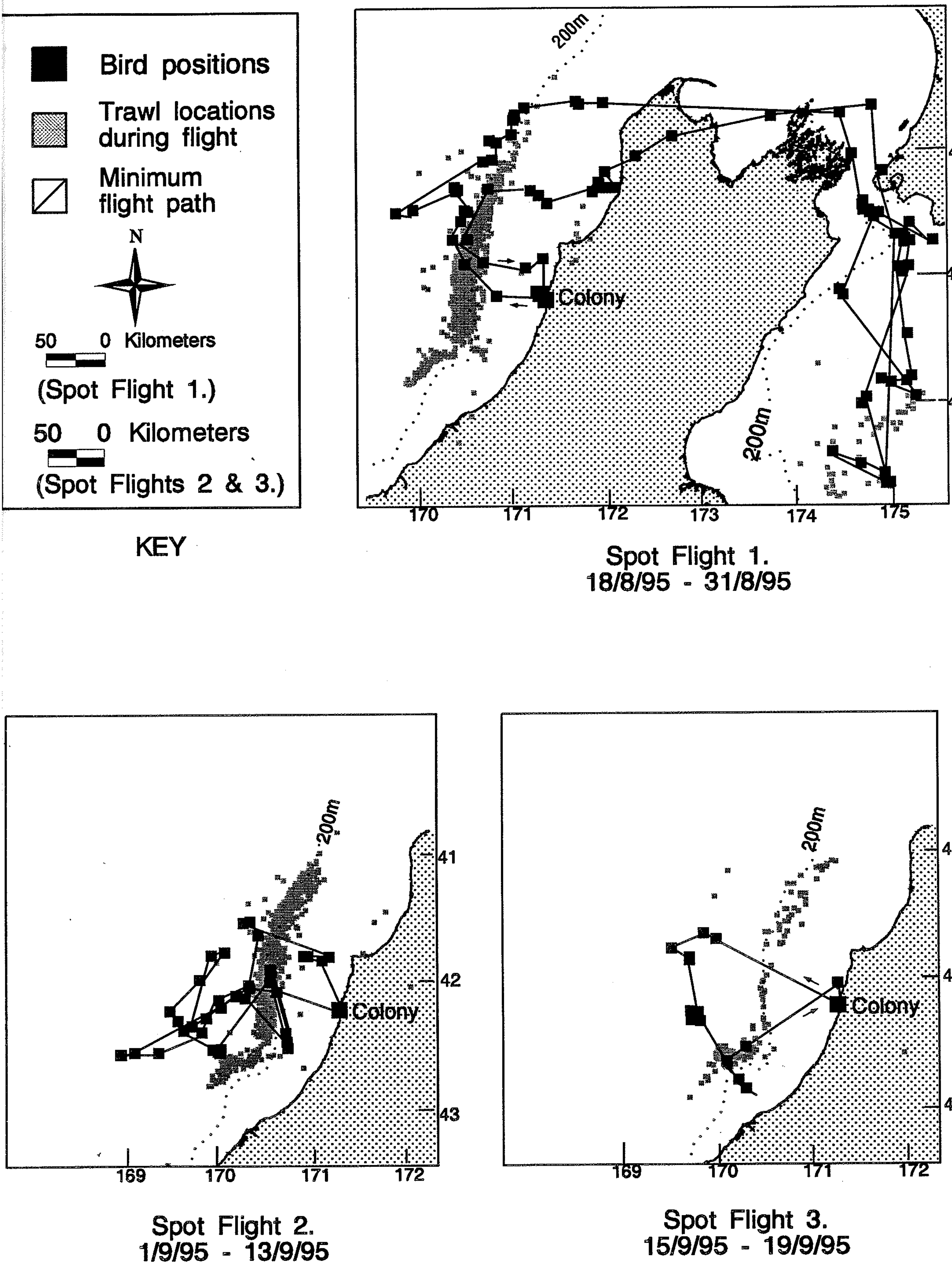

Figure 6. Satellite tracks of Spot.

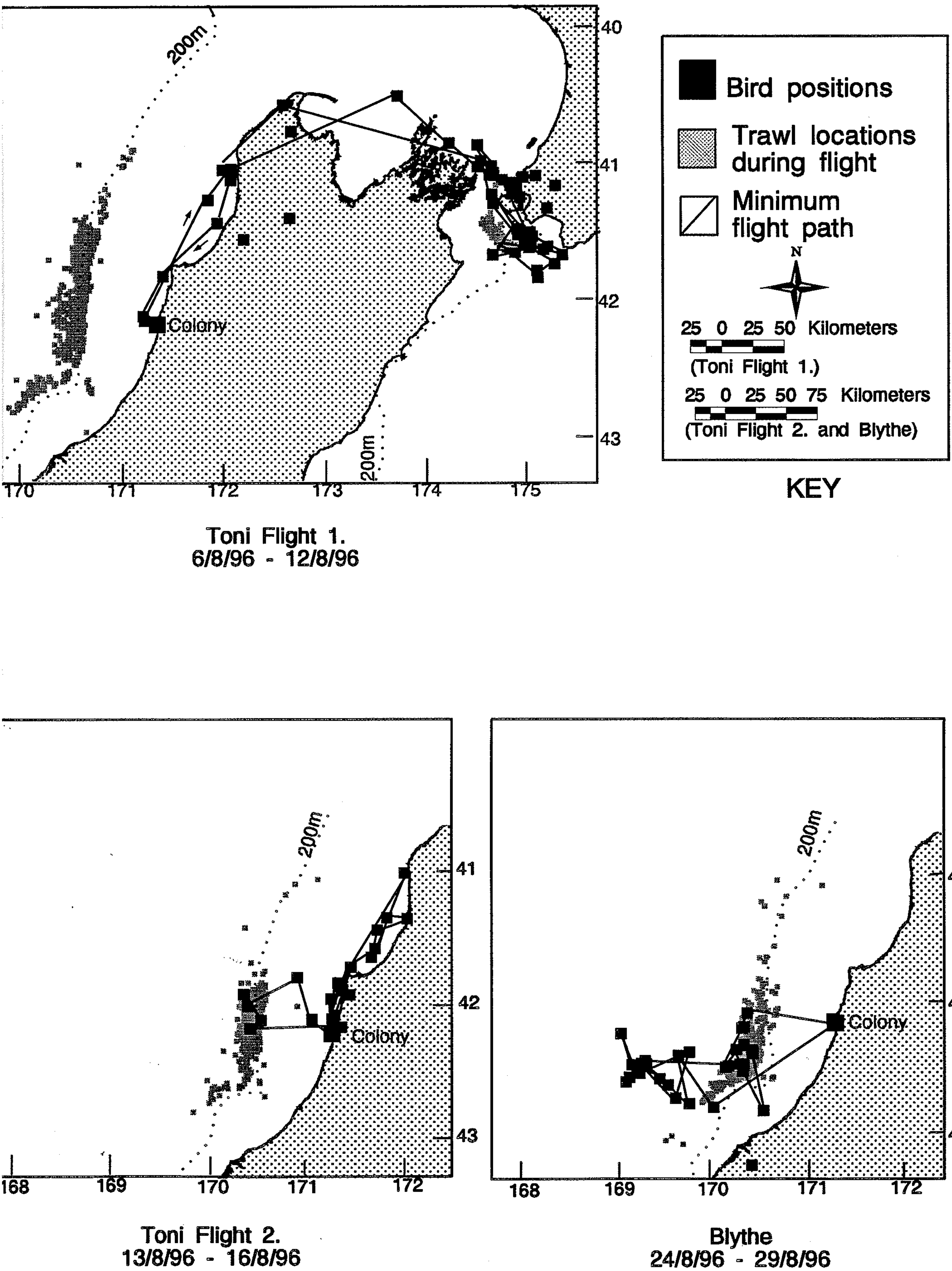

Figure 7. Satellite tracks of Toni and Blythe.

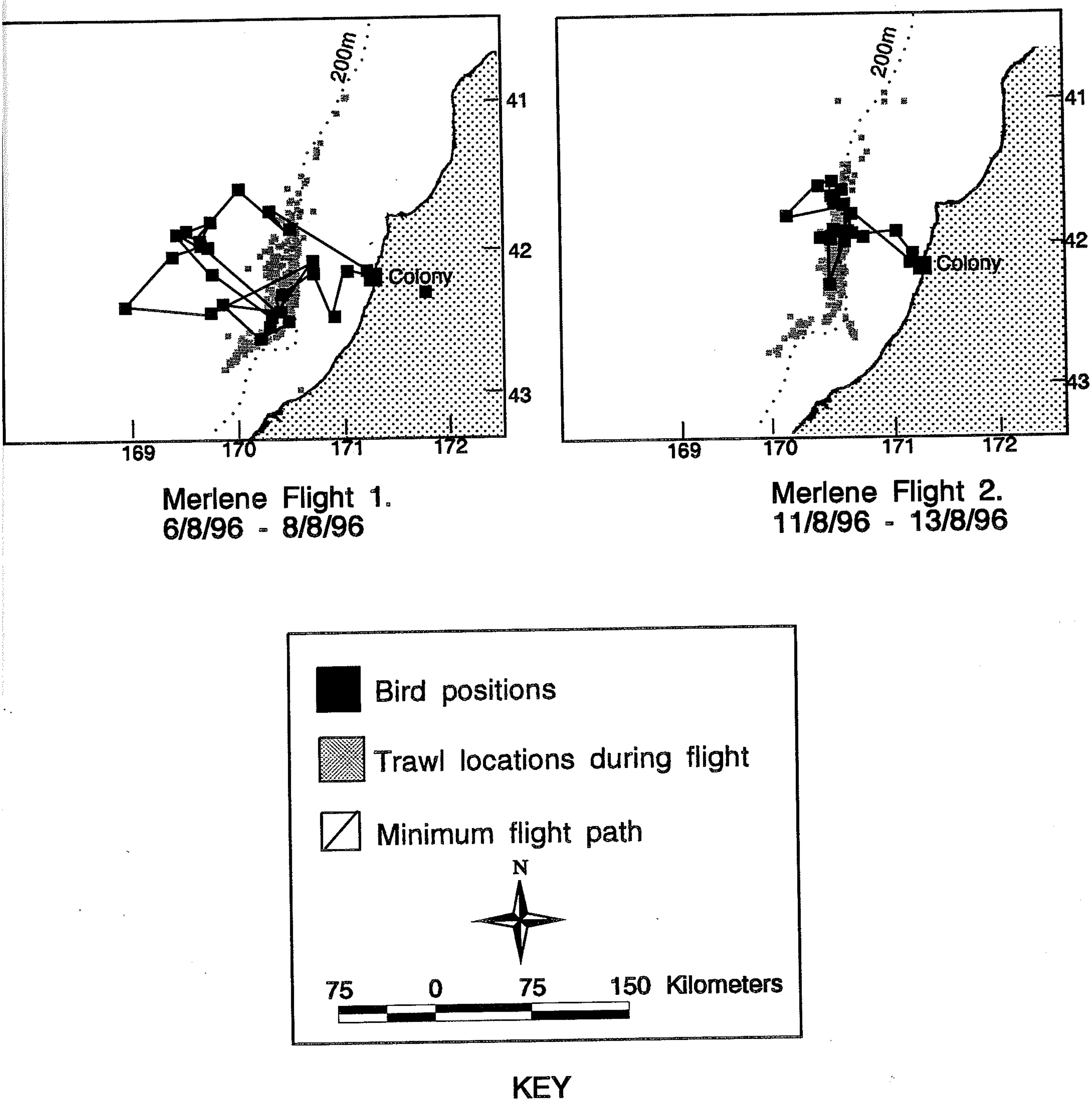

Figure 8. Satellite tracks of Merlene.

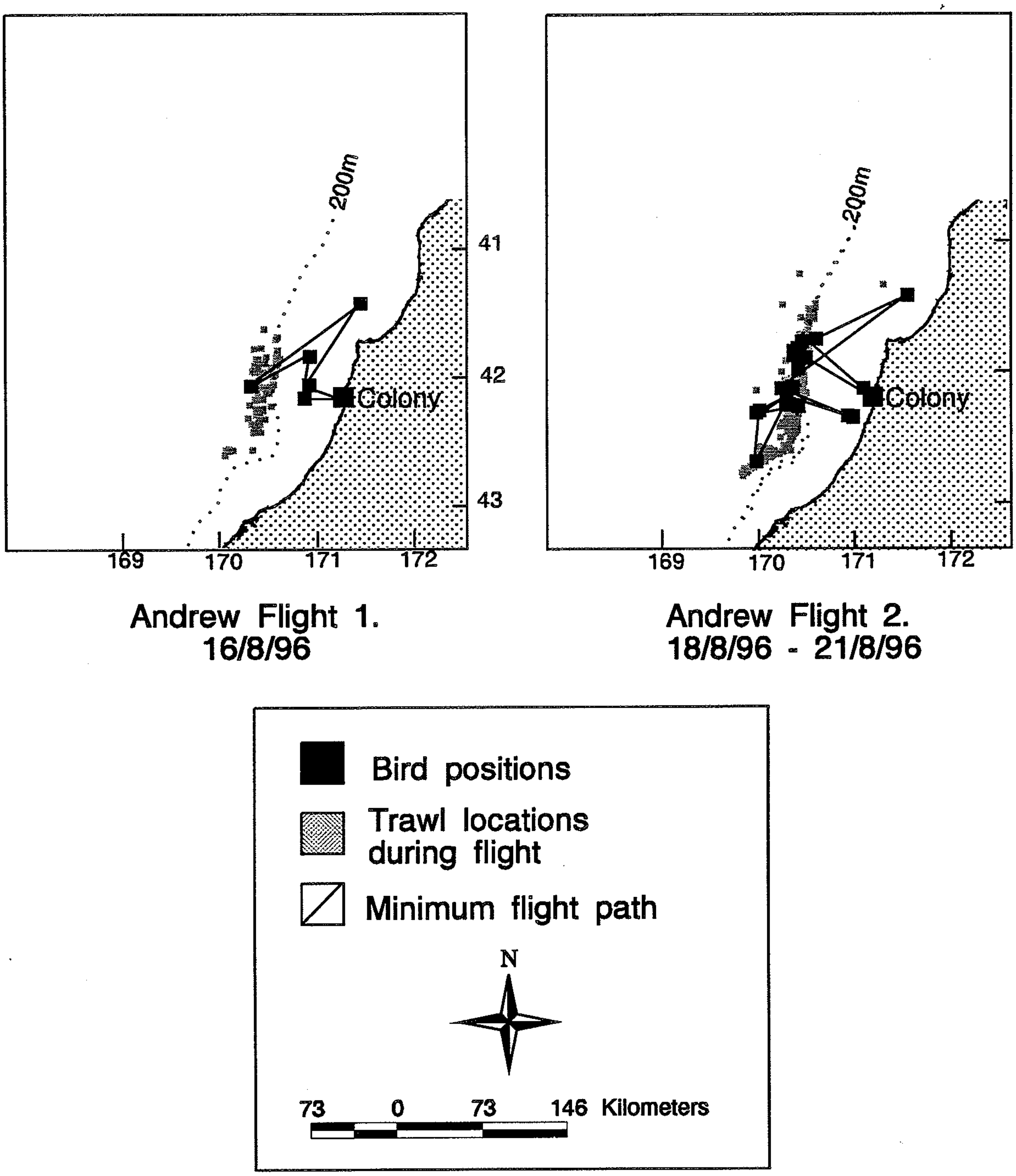

Figure 9. Satellite tracks of Andrew.

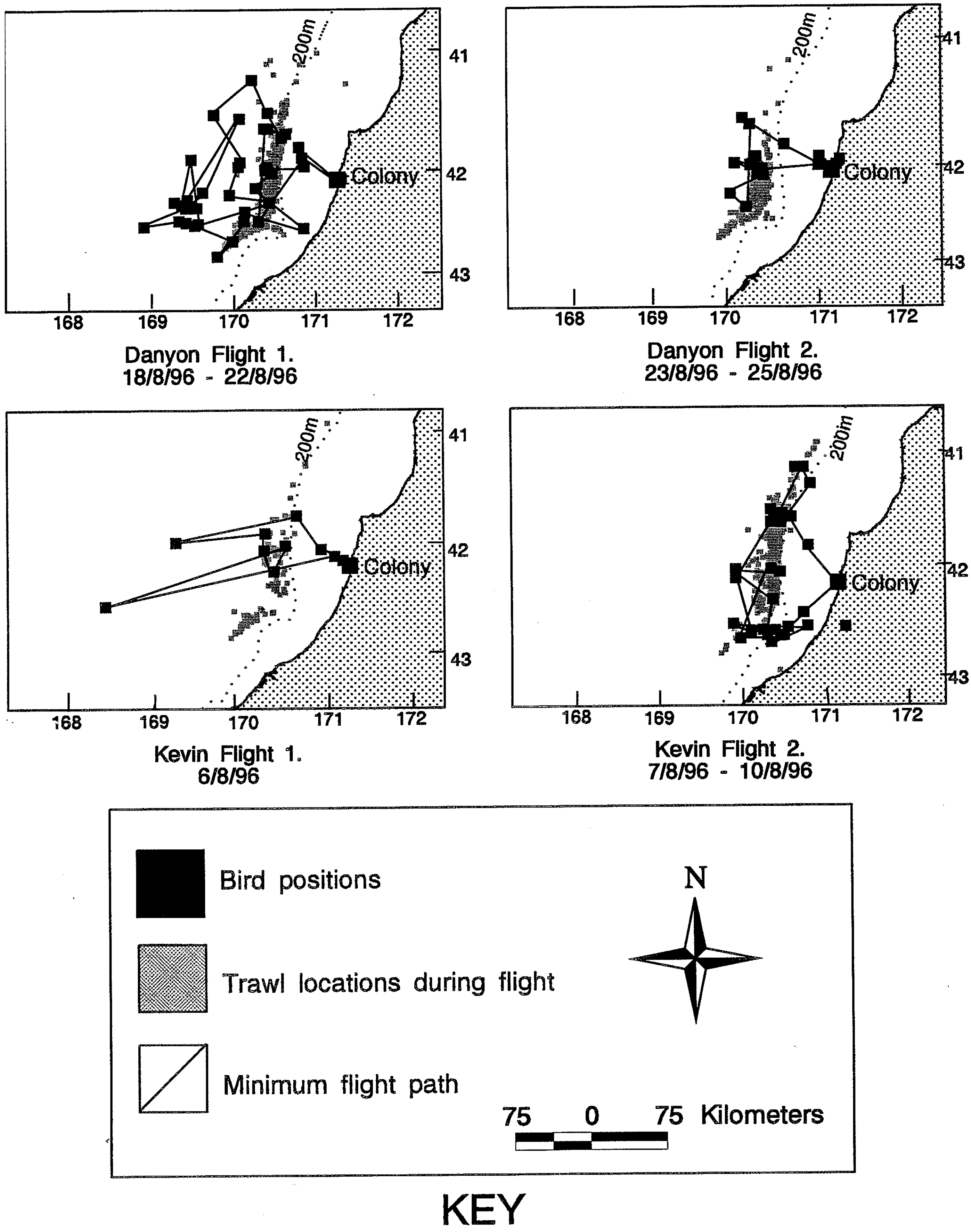

Figure 10. Satellite tracks of Danyon and Kevin.

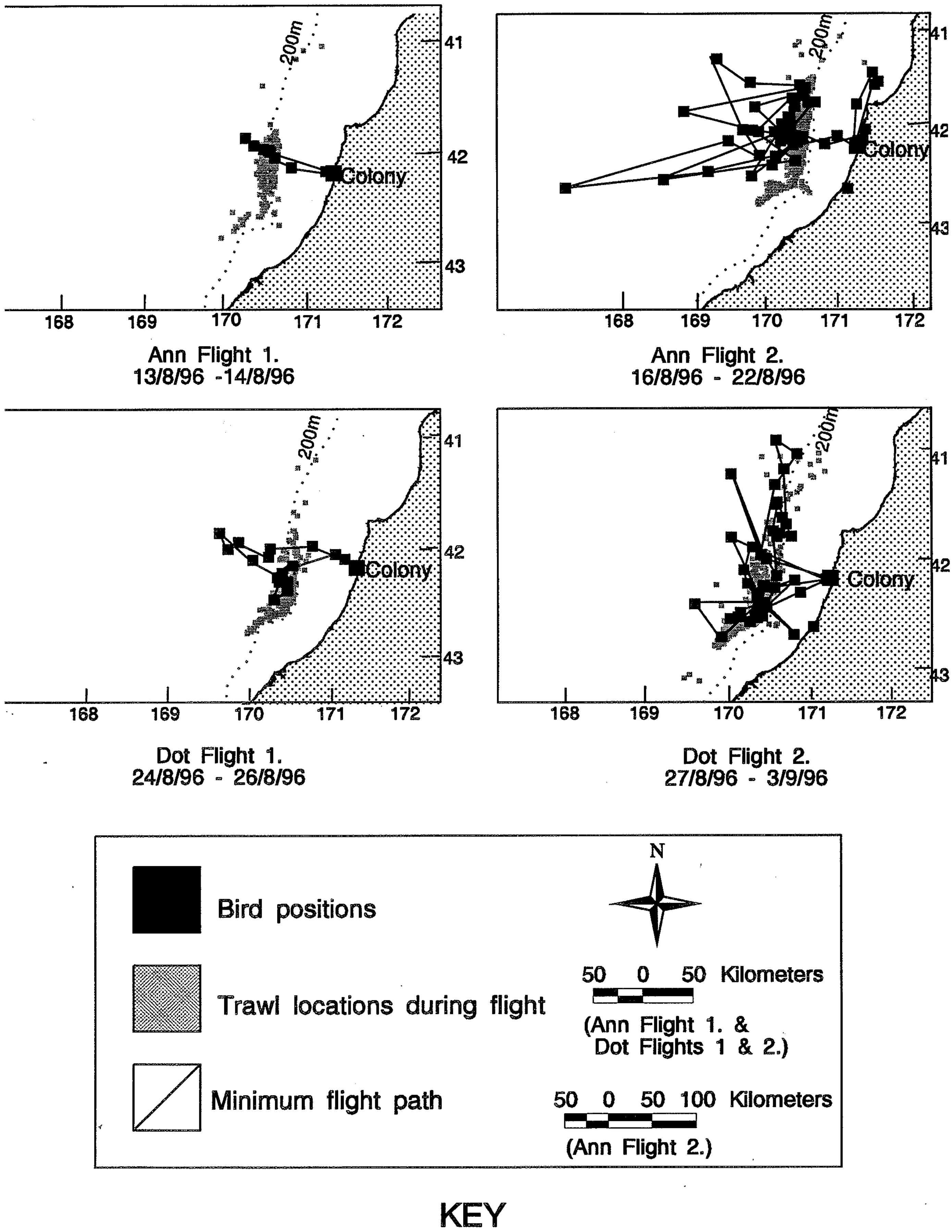

Figure 11. Satellite tracks of Ann and Dot.

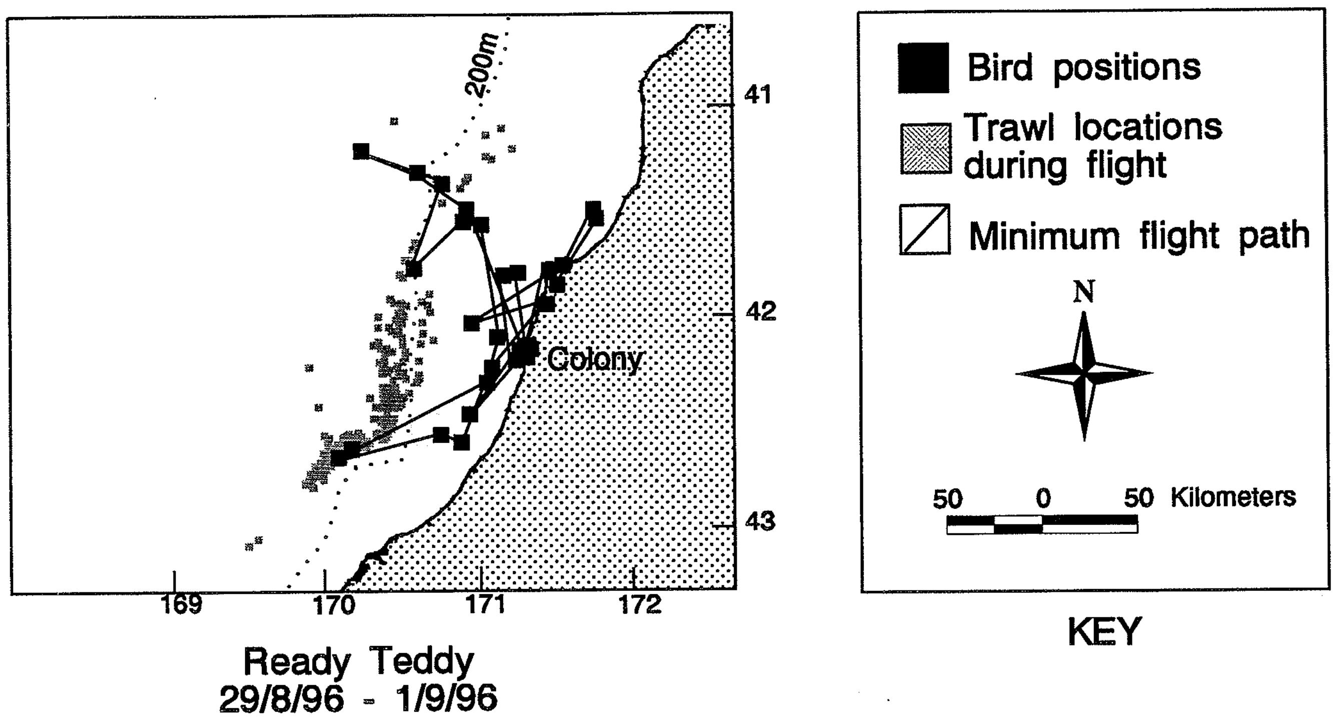

Figure 12. Satellite track of Ready Teddy.

Time spent in the vicinity of hoki fishing vessels

For each day of tracking, the number of bird positions recorded “close to” fishing vessels (<5 km from one or more trawls occurring on that day) were compared to the number recorded “distant from” fishing vessels (> 5 km from any trawl occurring on that day) (Table 2).

Table 2. Number of Westland petrel positions recorded “close to” and “distant from” trawls made by WCSI and Cook Strait hoki vessels.

Bird	No. close to trawls (<5 km)	%	No. distant from trawls (> 5 km)	%
Andrew	14	58	10	42
Kevin	16	50	16	50
Dot	21	49	22	51
Merlene	20	47	23	53
Sandy	16	39	25	61
Ann	20	38	32	62
Paul	32	31	71	69
Danyon	15	29	36	71
Blythe	9	28	23	72
Ready Teddy	3	12	23	88
Toni	7	11	54	89
Spot[1]	4	6	58	94

[1]Only Spot’s first tracked flight is included, as his second and third trips extended beyond the end of the hoki fishing season.

A survey at sea, undertaken in 1993 (Chapter 5), showed that vessels in the WCSI hoki fishery increase the number of Westland petrels within a 20 km radius. Using this distance in the present analysis, however, could have seriously over-estimated the proportion of time that birds were in proximity to vessels. Therefore, an arbitrary 5 km level was set in recognition of the flight speed of the birds and the movement of the vessels over each day. Positions recorded for birds as they left or returned to the colony, or were obviously travelling to feeding areas (eg Spot and Toni’s routes to Cook Strait) were excluded from this analysis. Where birds completed more than one flight, the data from all flights is combined. The number of positions recorded in the "close" and "distant" categories are assumed to equate to the proportion of time birds spent in those areas. The birds' positions reported by Argos were regularly spaced throughout the day, apart from a gap in satellite coverage which occurred between mid morning and mid afternoon. It cannot, of course, allow for the unknown movements of birds between satellite locations.

Although the average proportion of time that birds spent in the vicinity of the hoki fishing fleets was 33%, this was highly variable. Some birds spent about half of their time in the vicinity of fishing vessels, whereas others spent as little as 6-12% of their time there. This was not related to sex, as high and low proportions were recorded for both males and females. We did not have enough information about the prior breeding success of the tracked birds to assess whether age or breeding experience could be a factor. The two birds which travelled to Cook Strait spent the least time in the vicinity of fishing vessels. Despite the Cook Strait hoki fishing fleet operating in the same general area, these birds did not associate with vessels.

The proportion of time spent in the vicinity of hoki vessels also varied between trips of the same individual. The most marked examples of this were Merlene, whose first tracked flight was mostly west of the WCSI hoki fleet and whose second flight was mainly in the fishing area, and Ann whose first flight was mainly in the fishing area but whose second tracked flight was west of the WCSI fishing fleet (Figs. 8, 11).

The ratio of positions recorded close to hoki fishing vessels was similar during both night and day, indicating that the proportion of time Westland petrels spent in the vicinity of hoki fishing vessels was not influenced by daylight (Table 3).

Table 3. Number of Westland petrel positions recorded during the day and night, "close to" and "distant from" trawls by WCSI and Cook Strait hoki vessels.

	No. close to trawls (< 5km)	%	No. distant from trawls (> 5km)	%
Day	83	32	178	68
Night	94	30	215	70

Day = 0600hrs - 1800hrs. Night = 1800hrs - 0600hrs.

Apparent flight speeds in the vicinity of hoki fishing vessels

Although the average flight speed varied greatly between individual birds, mean flight speeds were significantly lower when in the vicinity of hoki fishing vessels (paired sample t-test; $t = 3.65$, $P = 0.005$) (Table 4).

Table 4. Average flying speeds of Westland petrels when "close to" and "distant from" trawls by WCSI and Cook Strait hoki vessels.

Bird	Speed close to trawls (< 5km) (km/h)	Speed distant from trawls (> 5km) (km/h)
Andrew	4	8
Kevin	6	14
Dot	11	16
Merlene	8	21
Sandy	11	17
Ann	17	23
Paul	4	9
Danyon	5	21
Blythe	10	15
Toni	8	10
Spot	15	11

NB. Due to the small number of records, it was not possible to calculate a flight speed close to vessels for Ready Teddy. He is therefore not included in this part of the analysis.

Flight speeds also varied between flights of the same individual. Again, the most marked examples were Merlene and Ann whose average speeds were much slower when in the vicinity of hoki fishing vessels. On their flights outside the WCSI fishing area, Merlene and Ann averaged 23 km/h and 25 km/h respectively; on their flights mostly within the fleet area they averaged 9 km/h and 3 km/h respectively.

Foraging trip length

Foraging trips of tracked birds ranged from one to 13 days (Table 1; Table 2 in Chapter 6.). Although the three trips of one day's duration were all within the WCSI hoki fishing fleet area, medium length and long foraging trips varied greatly; some mainly in the hoki fishing area, some mainly out of the fishing area, and some that moved in and out of the area occupied by the hoki fishing fleet.

The frequency distribution of foraging trip lengths was unimodal (Fig. 13).

Time spent near fishing vessels before return to the colony

A feature of most of the tracked flights was the time spent in the vicinity of fishing vessels at the end of a foraging trip. In 15 out of the 22 tracked flights (68%), satellite location data indicated that birds had stopped in the area occupied by the fishing fleet during the twelve hours before their return to the colony. The criteria used were; either recorded as <5 km from vessels for two or more consecutive satellite fixes or within 5 km of vessels at the time of a high quality satellite fix (Class 1-3)[4].

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[4] High quality satellite fixes are more likely to be from stationary birds.

Comparison of adult weights and controls

Weight of tracked birds

In 1995 all three birds tracked increased in weight between PTT attachment and recovery (Table 2 in Chapter 6). In 1996, six birds increased in weight, two remained the same weight, and only one lost weight, indicating that, in general, they fed successfully during their foraging trips (Table 1). The bird which lost weight had completed the longest trip of birds tracked in 1996, indicating that she may have had difficulty foraging.

Chick weight, wing length and fledging success

Chicks whose parent(s) were satellite tracked were compared with control groups of chicks whose parents were not handled during the season, apart from establishing egg-laying and chick-hatching (Table 5).

Table 5. Comparison of study and control burrow chicks.

	Fledging success 1995	Mean weight(g)/ wing length (mm) 15/11/1995	Fledging success 1996	Mean weight(g)/ wing length (mm) 11/11/1996
Study	100% (n=3)	1542/315 (n=3)	100% (n=7)	1758/316 (n=6)[1]
Control	64% (n=11)	1486/329 (n=7)	100% (n=10)	1930/325 (n=10)
significance	ns (P = 0.65/0.68)		ns (P = 0.17/0.49)	

[1] One study burrow chick had already fledged by 11/11/96.

The three chicks of birds satellite tracked in 1995 all fledged, as did the seven chicks of birds tracked in 1996. There was no significant difference between the weights and wing lengths of chicks of satellite tracked birds and a set of control burrow chicks, although there were small sample sizes in both years.

Foraging trip length

The duration of the 20 flights undertaken in August 1995 and 1996 by the satellite tracked birds was compared with the duration of trips undertaken by birds who were not carrying PTTs. A total of 74 such trips, recorded over August 1995 and 1996 were used in the analysis. These trips included some by birds which had been tracked previously. Spot's second and third trips are excluded from the analysis due to the lack of measured trips for untracked birds in September.

Birds spent significantly more time at sea when they were carrying a PTT; spending on average 4.45 days at sea compared to non-tracked birds which spent a mean of only 1.76 days at sea (t test; $t = -6.6$, $P = 0.00$). Whereas 93% of foraging trips of birds not carrying PTTs were of three days or less, only 45% of satellite tracked trips were of three days or less. Fifty percent of foraging trips by satellite tracked birds were of four to eight days duration (Fig. 13).

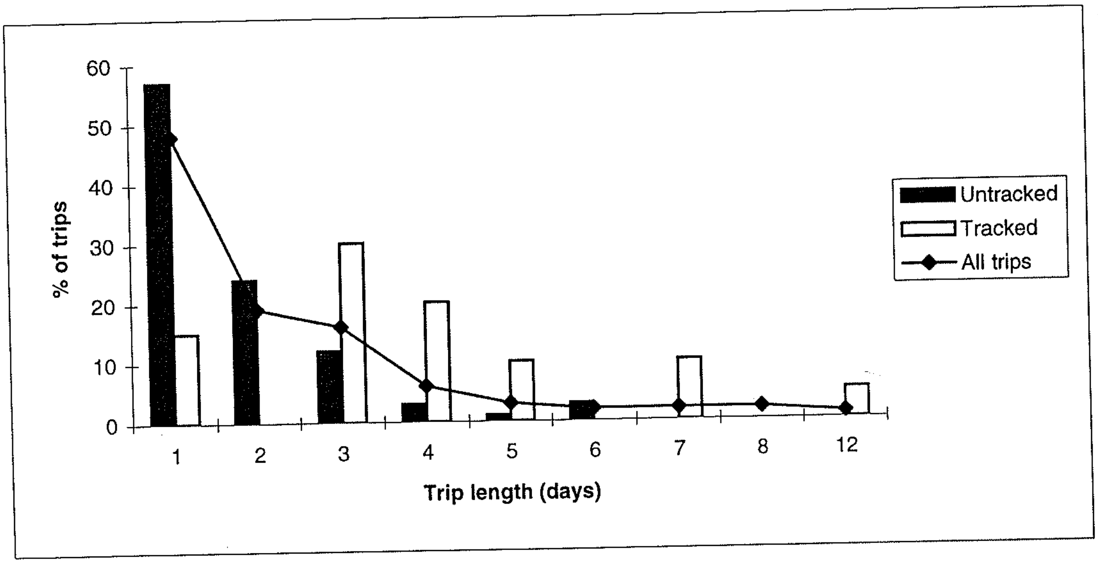

Figure 13. The frequency distributions of foraging trip lengths of tracked and untracked Westland petrels, August 1995 and 1996.

Discussion

Satellite tracking showed that some Westland petrels spent as much as half of their total foraging time in the vicinity of hoki fishing vessels and nine out of the 12 birds tracked spent at least 25% of their time there. These birds spent ample time in areas where fisheries waste could make an important contribution to their diet. Some Westland petrels, however, spent very little time associating with vessels and this suggests that the importance of fisheries waste may vary between individuals.

The above figures are an upper limit on the amount of time birds could be spending actually scavenging at vessels, as the methodology was not precise enough to determine when birds were exactly coincident with vessels in space and time. Fisheries data could not be more specific than trawls occurring on a given day, and the majority of positions received from Argos for birds in this study were of unknown accuracy. Over the relatively short distances that Westland petrels flew, location errors were likely to be significant and limit our ability to relate positions to fishing activity with precision.

The major problem in interpreting the implications of the amount of time spent around fishing vessels is that time spent is not necessarily proportional to food consumed. Waste from the hoki fishery is readily available and it may not take long for birds to consume large volumes. Although recorders have been developed which allowed researchers to detect times of ingestion in wandering albatross (Weimerskirch *et al.* 1994b), Westland petrels are too small for such devices and so, in the meantime, these problems seem intractable.

We cannot be certain of the extent to which the co-occurrence of fishing vessels and Westland petrels is coincidental. Hoki spawning occurs in winter when they school in large aggregations (Langley 1993). The WCSI and Cook Strait hoki fisheries are concentrated on these spawning aggregations which largely coincide with the 200 m depth contour. The upper part of the continental slope between 200 and about 800 m is a diverse and rich marine habitat. Upwelling of deep, nutrient-rich water often occurs along the upper edge of the continental slope, especially on the West Coast, leading to a high productivity of plankton and fishes (Ayling & Cox, 1982). This zone is the source of much of the Westland petrel's natural prey (Chapter 3) and presumably during their breeding season Westland petrels would forage extensively there regardless of the fishery.

It is not possible to separate the effects of the hoki fishery and the shelf break on the distribution of Westland petrels at sea. However, we know from diet studies (Chapter 3) that the relationship between Westland petrels and fishing vessels is not merely coincidental as fisheries waste forms a significant part of their diet. The slower average flight speeds recorded for birds in the vicinity of fishing vessels is further evidence of extensive scavenging.

Walker *et al.* (1995) point out that calculated speeds and distances are affected by the interval between satellite locations. Frequent satellite locations closely map a bird's flight, whereas infrequent locations underestimate distance and speed because they miss many small changes in direction. With an average of only eight locations per day, our estimates of flight speed are likely to be seriously underestimated. However, it is the relative flight speeds close to and away from vessels that are of most interest in this study, rather than the actual flying speeds attained.

We did not observe any difference in behaviour by night and day in the Westland petrels which were tracked by satellite either in their average flight speeds or the proportion of time spent in the vicinity of fishing vessels. This suggests that Westland petrels scavenge around fishing vessels equally by day and by night. Whereas most natural prey is only available at night, due to the diurnal vertical migration of prey to and from the surface layers (Imber 1976), waste from the hoki fishery is available continuously, 24 hours a day (A.N.D. Freeman pers. obs.).

Recent work on the Westland petrel's diet has shown that fisheries waste forms over 50% of the solid food brought back to the colony during the hoki fishing season (Chapter 3). An unavoidable bias in diet sampling at seabird colonies is that the food consumed most recently can be over represented in the diet samples. In

Procellariiformes, food is digested rapidly and some converted to oil, so only the most recently ingested food is detected by diet sampling. As 68% of tracked flights stopped in the WCSI hoki fishery area in the twelve hours immediately prior to the bird's return to the colony, but on average birds only spent a third of their time in the vicinity of vessels, it is likely that diet sampling over estimated the importance of fisheries waste. The amount of time birds spent outside of the hoki fishing areas suggests that, despite the large scale fishery, Westland petrels continue to forage over much wider areas than those occupied by the hoki fishing fleets.

The methods of reporting fishing activity meant that there was no way of assessing the relationship of satellite tracked Westland petrels to other fisheries. Small fisheries of a few thousand tonnes for several species, including red cod *Pseudophycis bachus*, barracouta *Thyrsites atun* and ling *Genypterus blacodes* occur off the West Coast of the South Island (Annala & Sullivan 1996), and Westland petrels also scavenge from these fisheries (Chapter 3). Their importance to Westland petrels is unknown.

Unlike the foraging trips of pelagic species described by Weimerskirch *et al.* (1994a), the frequency distribution of Westland petrel foraging trips was unimodal, reflecting their shelf and slope foraging habits. Co-occurrence with fishing vessels was observed in trips of all durations and consequently, fisheries waste is probably important in both adult maintenance and chick provisioning. However, as most satellite-tracked Westland petrels visited the WCSI hoki fishing fleet in the last 24 hours of their trips, the fishery may be most important in chick provisioning.

This research has shown that caution must be taken in interpreting satellite tracks as natural behaviour. Westland petrels carrying PTTs increased the length of their foraging trips markedly compared with birds that were not carrying transmitters. This contrasts with satellite tracking studies on wandering albatross and light-mantled sooty albatross where transmitters were not considered to have altered the behaviour of the birds (Weimerskirch *et al.* 1993; Weimerskirch & Robertson 1994), and radio tracking studies of Parkinson's petrel *Procellaria parkinsoni,* where comparisons of meal size and frequency between tracked and untracked birds suggested birds were foraging normally (Scofield, 1989). However, negative effects of tracking on foraging efficiency and speed have been noted in some other studies. For example attachment of PTTs during incubation significantly increased foraging trip duration in Adelie penguins (Clarke *et al.* 1994) and effects have been well documented in radio tracking studies on other bird taxa (eg. Gessaman & Nagy 1988; Boag 1972). Other than increasing their foraging trip lengths, we cannot know whether or not satellite tracked Westland petrels behaved normally. Satellite tracking did not appear to have any adverse affect on adult weight or chick success.

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Chapter 8.

General Discussion

Importance of Fisheries Waste in the Diet of Westland Petrels

In this study I attempted to establish how important fisheries waste is in the diet of Westland petrels using three different approaches; diet sampling, a survey of Westland petrels at sea and tracking individual birds. The study focussed on the West Coast South Island hoki fishery due to its size, and its proximity to the Westland petrel's breeding grounds.

The diet study (Chapter 3) showed that during the hoki fishing season, fisheries waste accounted for more than half by weight of the solid food brought back to the colony. After the hoki season, fisheries waste contributed only about a quarter by weight of the solid food brought back to the colony as birds switched to more natural prey, and scavenged a wider variety of fish species, presumably from smaller, inshore fishing vessels. The electrophoretic technique iso-electric focusing increased the number of fish samples that could be identified and consequently the diet was interpreted differently than had only traditional diet analysis been used (Chapter 4). Iso-electric focusing revealed that fisheries waste is much more prominent in the diet of Westland petrels than was indicated by analysis of hard prey remains. Regurgitation and water offloading essentially sample the most recent food consumed and, as satellite tracking indicated that most (68%) of tracked Westland petrels stopped and fed at the hoki fishery in the 12 hours before returning to shore, the diet study is likely to have over estimated the importance of fisheries waste.

The survey of Westland petrel distribution at sea, which was conducted off the West Coast of the South Island (Chapter 5), showed that vessels in the hoki fishery influenced the distribution of Westland petrels. Despite the proximity of the fishing grounds to the petrel's breeding colonies, only a small proportion of the Westland petrel population appeared to be utilising this food resource at any one time. During the survey, Westland petrels were only observed over water depths of 250 - 780 m and were not seen near fishing vessels in shallower water (100 - 200 m). This suggested that Westland petrels may select foraging areas primarily on natural features, such as water depth, and only if fishing vessels are in the same area are Westland petrels attracted to them. Shallower waters were not adequately sampled, however, and satellite tracking subsequently showed that, on occasions, birds may spend considerable time inshore. Presumably, the fisheries waste obtained after the end of the hoki fishing season is taken comparatively close inshore from the small, inshore vessels which are operating at that time. Although Ryan & Moloney (1988) found that white chinned petrels *Procellaria aequinoctialis* were more abundant around trawlers near the shelf edge, Ridoux (1987) cited in Ridoux (1994) reported that these petrels will follow whales in to coastal areas where they normally do not forage, thus it seems likely that fishing vessels could attract Westland petrels into shallower water than they might normally use.

The survey at sea could not distinguish between breeding and non-breeding birds and was limited in the area it covered. Significantly, it did not cover areas west of the hoki fishing fleet where satellite tracking in later seasons showed that Westland petrels spend significant amounts of time. The survey could not be conducted at the same time as diet sampling, or in the same years as satellite tracking.

Individual birds were tracked on their foraging trips, first by VHF radio telemetry and later, when this proved inadequate, by satellite tracking (Chapters 6 & 7). Radio telemetry would have had advantages over satellite tracking if the birds had stayed within radio reception range. Unlike satellite tracking, where locations are only provided every few hours, continuous monitoring is possible with radio tracking. This would have enabled us to better estimate the proportion of time that birds spent in the vicinity of hoki fishing vessels.

There was considerable variation in the amount of time that tracked birds, all with dependent chicks ashore, spent in the vicinity of hoki fishing vessels. Some birds spent as much as half their time near the WCSI fishing fleet, and nine out of the twelve birds satellite tracked spent at least 25% of their time there. Three birds however, two of which visited Cook Strait, associated little with vessels. The time spent in the vicinity of vessels did not appear to be related to sex, length of foraging trip or time in August/September when birds were tracked. These figures provided an upper limit on the amount of time birds could have spent actually scavenging at vessels, as the methodology was not precise enough to determine when birds were coincident with vessels.

The majority of tracked birds moved in and out of the hoki fishing area during their flights. This may partly explain the low number of Westland petrels observed during the West Coast survey at sea as there is presumably a high turn over of birds around vessels. Many tracked birds foraged west of the WCSI hoki fishing fleet, outside of the area surveyed, and two left the west coast entirely, travelling to Cook Strait and beyond. On occasions, birds were also tracked close in shore. However, most tracked birds concentrated on the rich neritic waters of the shelf break and slope (c. 200-800 m water depth). As the WCSI hoki fishery also largely coincides with the 200 m depth contour, it was not possible to separate out the effects of the hoki fishery and the shelf break on the distribution of Westland petrels at sea. As this zone is the source of much of the Westland petrel's natural prey, they would presumably forage there whether or not fishing vessels were present. Diet studies confirmed, however, that the co-occurrence of Westland petrels and fishing vessels is not merely coincidental, as fisheries waste forms a significant part of their diet.

Fisheries waste is a large component (over 50% by weight in the hoki fishing season) of the solid food brought back to the colony and fed to chicks. What though is the importance of fisheries waste to the diet as a whole? What contribution may fisheries waste be making to the proventricular oil fed to chicks, and to the maintenance of adult condition? What proportion of the population is scavenging at vessels?

Due to limitations of the methodology, particularly the difficulty in relating time spent foraging to food consumed, and the small number of birds used in satellite tracking, the results from this study are only indicative. However, some inferences may be made.

A majority of the breeding population of Westland petrels frequent the WCSI hoki fishery. If time spent in an area is proportional to food consumed there, fisheries waste may provide about one third, on average, of their total diet during the hoki fishing season. Time spent is not necessarily proportional to the importance of a food source, however, or even to the amount of food obtained. For example, fisheries waste may be obtained so easily that Westland petrels can acquire all their needs in a short space of time. Westland petrels do, however, continue to forage on natural prey and presumably this is what they are doing during the time spent away from fishing vessels. The satellite tracking results also indicate that part of the breeding population, perhaps one quarter, may never, or seldom, scavenge around hoki fishing vessels. In the non-hoki season, fisheries waste makes a smaller contribution to the Westland petrel's diet. The situation appears to be one of opportunistic use of a readily available resource rather than dependence.

Why do Westland Petrels Forage for Natural Prey?

If fisheries waste is readily available, why do Westland petrels continue to forage for natural prey? There are two competing hypotheses for which no supporting data are currently available.

First, there may not be an over abundance of waste available to scavenging birds, meaning that only part of the diet can be supplied by fisheries and birds are obliged to forage elsewhere. This is thought to be the case in the North Sea where the numbers of seabirds that could be supported by fishery waste seem to be considerably fewer than the numbers of scavenging seabirds present around vessels, indicating that much of the diet of fulmars *Fulmarus glacialis*, large gulls *Larus* spp. and gannets *Morus bassanus* must come from other sources (Dunnet *et al.* 1990). Experiments to assess the proportion of waste consumed by seabirds would help determine if this is also the case in the hoki fishery (see Future Studies section).

Fish is generally higher in calorific value than squid, and has a higher proportion of protein and calcium (Clarke & Prince 1980). There is evidence that calcium may be a factor limiting chick growth in large birds. Calcium availability has been suggested as the reason for the longer fledging period of the grey headed mollymawk *Diomedea chrysostoma* which feeds its chick largely on squid, compared with the black browed mollymawk *Diomedea melanophrys* which eats more krill (Clarke & Prince 1980). Perhaps calcium supply is also a critical factor in allowing Westland petrel chicks to fledge in 120 - 140 days (Marchant & Higgins 1990), unlike the smaller grey petrels *Procellaria cinerea* which feed more on squid and take 147 days to fledge (Marchant & Higgins 1990). However, fisheries waste generally provides a limited range of food types and may in some way be an inadequate diet that requires supplementing from other sources. J. A. (Sandy) Bartle's suggestion that the feather malformation observed in some Westland petrel chicks could be the result of a poor quality diet comprised of fisheries waste follows this argument (refer Chapter 1). Unfortunately, there is not enough information on the occurrence of feather malformation, or its relationship to diet to test this suggestion. The alternative explanation of a genetic defect causing feather malformation is also untested.

Alternatively, fisheries waste may be only a second choice food. Camphuysen *et al.* (1995) provide several examples where fishery discards are mainly exploited when natural food is less readily available. They report that large flocks of kittiwakes *Rissa tridactyla* were observed off the east coast of Britain at times when relatively few birds could be attracted to fishing vessels and high densities of fulmars were observed near large fisheries when few birds were observed scavenging. Data on lesser black-backed gulls *Larus fuscus* in the Netherlands showed that poor breeding years correlated with years in which discards predominated in chick foods, whereas good years coincided with years in which naturally acquired herring *Clupea harengus* was fed to chicks. Discards seemed to be only a supplementary food for these birds and were only partially successful in maintaining breeding success (K. Camphuysen pers. comm.). In kittiwakes, offal apparently allowed some birds to breed successfully in years when their natural sandeel *Ammodytes* prey was scarce. Diets of most kittiwakes breeding in Shetland did not shift from sandeels to discards and breeding attempts in these birds failed whereas the only 'successful' colony of kittiwakes in Shetland during the bad sandeel years appeared to feed mainly on offal (Hamer *et al.* 1993; Heubeck 1989 & Walsh *et al.* 1991 cited in Camphuysen *et al.* 1995).

It is possible that fisheries waste is most important to Westland petrels in 'poor' years and helps to even out annual variations in breeding success. The Westland petrel's breeding success (percentage of eggs from which chicks fledged) has varied considerably over the years it has been monitored. In the years 1976 - 1991 it averaged 39% (range 20-63%) (Department of Conservation 1996) and in 1991-1996 it averaged 50% (range 38-63%) (pers. obs.). An earlier study found that breeding success in 1970 and 1971 was only 5.7 and 3% respectively (Baker & Coleman 1977). However, the authors attributed this to chicks being 'birded' (taken for human consumption) in the late chick stage and this is a more likely explanation than any relationship to poor food supply.

An indication that fisheries waste is more important to Westland petrels in 'poor' years might be if Westland petrel breeding success is less variable than in species that do not forage on fisheries waste while breeding. Unfortunately, there are few species with which to make useful comparisons, and breeding success is generally poorly known among petrel species. Of species occurring around the New Zealand mainland, one might compare the breeding success of Westland petrels to that of Parkinson's petrels *Procellaria parkinsoni,* sooty shearwaters *Puffinus griseus* or grey faced petrels *Pterodroma macroptera gouldi*, but these species also scavenge fisheries waste and there are no detailed data on their breeding success. Generally, years of poor breeding success in these species seem to be attributable to predation and food shortage is not implicated (refer species accounts in Marchant & Higgins 1990).

What are the Implications of the Current Level of Waste Use if the WCSI Hoki Fishery Changes?

As the WCSI hoki fishery is apparently the fishery most used by Westland petrels during their breeding season, changes which result in less waste from this fishery are the most likely to have an affect on Westland petrels. Such changes could include movement of vessels to other fishing grounds (such as the movement to Cook Strait following the discovery of new spawning grounds there), reduction in the number of surimi vessels in favour of smaller filleting boats, and/or a reduction in the number of vessels without meal plants which process waste into fish meal for fertiliser. This mixture of biological and economic factors have probably already reduced the volume of fisheries waste discharged from the WCSI hoki fishery over the last few years (refer Chapter 1). Other changes which could reduce the volume of waste available are quota reduction or economic factors affecting the profitability of WCSI hoki fishing. The likelihood of such changes is unknown.

The impact that a reduction in fisheries waste would have on the Westland petrel population may depend on a number of factors. The first of these is the ease with which Westland petrels can obtain waste. This may depend on their hierarchical status among birds attending vessels as presumably smaller scavenging species would be most affected by reduced volumes of waste.

Experimental discarding experiments (where the fate of 'waste' thrown overboard is recorded) have been used in several North Sea studies to assess the dominance hierarchy of birds scavenging at vessels. Such studies have found that although there are differences in the size of waste portions selected by different species, this only partly reduces competition and, in general, the success rate of smaller birds in acquiring waste tends to be lower than that of larger species (Camphuysen *et al.* 1995). Warham (1996) and Weimerskirch *et al.* (1986) note that the same sort of hierarchy is present in Southern Ocean species around a localised food resource where the largest species, usually wandering albatross *Diomedea exulans* or black browed mollymawks, dominate. Off the West Coast in winter, the most common species recorded scavenging at vessels are wandering albatross, northern giant petrel *Macronectes halli*, shy mollymawk *Diomedea cauta cauta*, Buller's mollymawk *Diomedea bulleri*, black browed mollymawk, Westland petrel, grey faced petrel and cape pigeons *Daption capense* (Langlands 1989; pers. obs.). Of these species, the larger albatross, mollymawks and giant petrels tend to dominate the Westland petrels, but the aggressive Westland petrels with their relatively heavy bills dominate the smaller ones (pers. obs.). There is no quantitative data on this dominance hierarchy or on the success of petrels at scavenging in the hoki fishery.

Interspecific competition may play an important role in the responses of seabird populations to changing fisheries practices. For example, the volume of waste consumed by great skuas *Catharacta skua* in Shetland varied depending on the availability of sandeels, their preferred prey. When sandeels were scarce and skuas took a disproportionate share of available discards, gulls were thought to turn to other food sources (Furness & Monaghan 1987). Therefore, Westland petrels may not only be affected by changes in their own food supply, but also by changes in the food supply of competing scavengers.

The WCSI hoki fishery may have secondary effects on the food available to Westland petrels. For example, Furness (1978) ascribed the increase in seabird numbers in the South East Atlantic partly to overfishing of predatory species. While fishing provided some waste for scavenging seabirds, it also allowed a greater proportion of sandeel production to be taken by seabirds instead of fish predators. Because only one gram of fish tissue is produced for every 10 to 20 g of fish prey eaten, even a slight reduction of the fish standing crop releases a disproportionate amount of fish prey for seabird consumption; probably in the region of five to ten times the amount of waste resulting from the processing of the catch (Furness 1978). Fisheries waste, however, has received greater attention as a food source made available directly to seabirds by fishing.

A large quantity of hoki is removed by trawling each year. This could result in release from competition for Westland petrels whose natural diet is comprised partly of myctophids which are also important in the diet of hoki (Kuo & Tanaka 1984). This is unlikely, however, as most adult hoki reside on the Southern Plateau (away from the Westland petrel's foraging grounds) outside of the spawning season, and hoki do not appear to feed while spawning (Livingston 1990).

The present research has shown that the relationship between Westland petrels and the WCSI hoki fishery is probably one of opportunistic use of a readily available resource, rather than one of dependence. A key factor in whether or not Westland petrels would be negatively affected by a decline in the availability of fisheries waste is how easily they could turn to alternative food sources. There are several features of the Westland petrel's breeding biology and foraging ecology that suggest that they could compensate for a reduction in waste from the hoki fishery by switching to other sources of waste and increasing the quantity of natural prey caught.

Westland petrels continue to feed on natural prey, even at the height of the hoki fishing season. Satellite-tracked birds which spent the greatest amount of time in the vicinity of the WCSI fishing fleet still spent 40 to 50% of their time away from vessels, presumably foraging for natural foods. There is no evidence that the Westland petrel's natural foods have decreased in abundance. After the hoki fishing season, when Westland petrels are feeding larger, more demanding chicks, they switch to more natural prey, and scavenge at smaller, in shore fishing vessels, suggesting that Westland petrels are quite adaptable in their foraging. They are probably similar to the closely related white chinned petrel in this respect. The foraging techniques used by white chinned petrels are diverse; feeding by day and night, using surface seizing and deep plunging, displaying aggressive behaviour at limited food sources, and associating with vessels and cetaceans (Ridoux 1994), all behaviours that suggest an ability to take advantage of different feeding opportunities.

Although the foraging trip lengths of satellite tracked birds were, on average, longer than un-tracked birds, presumably because it took them longer to obtain food, all their chicks still fledged with normal weights and wing lengths. This suggests that Westland petrels may be able to sustain increased foraging trip lengths (which could be necessitated by a reduction in available food through decreased volumes of fisheries waste), without detriment to their breeding success.

White chinned petrels have been shown to forage up to c. 1200 km from their nests while breeding (Ridoux 1994). Satellite tracking showed that breeding Westland petrels are capable of similar distances. At least some Westland petrels fly as far as Cook Strait while rearing chicks. 'Spot' flew more than 800 km from the colony on his trip through Cook Strait and down the east coast. This shows that Westland petrels are not restricted to West Coast waters while breeding and can forage over much wider areas than that occupied by the WCSI hoki fishery. Most birds tracked, however, foraged within 200km of the colony.

Despite the constant supply of fisheries waste during the hoki fishing season, Westland petrel breeding success has varied over the last 20 years. Breeding success has been relatively high in recent years even though the amount of waste discharged from the WCSI hoki fishery has presumably decreased over the same period due to the reduced catch on the West Coast (refer Chapter 1). Therefore it appears that other factors are more important to breeding success than the quantity of fisheries waste available. These could be environmental factors affecting natural prey abundance or feeding success at any stage of the year.

Finally, when Westland petrel chicks fledge in November/December each year, the hoki fishing season has been over for two months. All young birds must therefore learn to feed without the waste provided by this large scale fishery.

The above factors suggest that although waste from the WCSI hoki fishery forms a large proportion of the food fed to chicks, Westland petrels could adapt to changes in the fishery that reduced waste availability, without any adverse effect on their breeding success or population level. However, the WCSI hoki fishery coincides with chick guarding, the most constraining part of the breeding season, and the importance of fisheries waste at that stage and during incubation remains unstudied.

Could Other Factors Account for the Increase in the Westland Petrel Population?

The seemingly opportunistic nature of Westland petrel's scavenging at vessels in the WCSI hoki fishery, rather than obvious reliance, and the lack of correspondence between breeding success and either yearly differences in the diet or the volume of waste available, suggest that other factors besides the WCSI hoki fishery are more important in determining breeding success from year to year, and presumably over longer periods.

Factors operating on the colony, such as predator control, control of herbivores, and the demise of (illegal) 'birding' may have contributed to the Westland petrel's population increase. The greatest density of Westland petrel burrows is located under northern rata

Metrosideros robusta stands which provide rough bark and sloping boughs ideal for petrels to climb for take-off. Control of possums *Trichosurus vulpecula* and goats *Capra hircus* may have contributed to population expansion by controlling browsing, thus improving the quality of nesting habitat, and preventing trampling of burrows.

Potential predators recorded at the colony are cats *Felis catus*, dogs *Canis familiaris*, stoats *Mustela erminea*, ship rats *Rattus rattus*, Norwegian rats *Rattus norvegicus* and weka *Gallirallus australis*. Chicks, and occasionally adults, have been taken by cats, dogs and weka (Department of Conservation 1996). There is now a regular programme of predator control at the colony. Although the extent to which 'birding' occurred on the Westland petrel colony is unknown, the fact that it was still taking place as late as the 1970s (Baker & Coleman 1977) indicates that it was possibly a factor influencing the population over a long period of time.

Future Studies

There are a number of areas of further research that would improve our understanding of the role of fisheries waste in sustaining the population level of Westland petrels.

The diet and tracking components of this study were carried out on only one sub colony. It is by no means certain that birds from different subcolonies feed in the same areas, or are therefore affected by the same conditions. For example, Weimerskirch *et al.* (1988) marked breeding black browed mollymawks from different colonies at Kerguelen Island with different coloured dyes. Birds from the different colonies were seen over different parts of the Kerguelen shelf, suggesting that they fed in different places. It is possible that birds from some Westland petrel subcolonies feed on fisheries waste more than others, and diet sampling in other areas would establish whether or not the present diet study was representative of the population as a whole.

Similarly, this study was largely confined to the August-October chick rearing period. It is possible that fisheries waste is more or less important during other stages of the Westland petrel breeding cycle. It may also be more or less important to non breeders. There are difficulties with diet sampling on the colony during incubation and guarding, however, as adults are susceptible to disturbance (pers. obs.). Incubating birds, which rely on their latest food intake and body reserves for long periods, should not be sampled while on their nest. Instead, it may be possible to catch birds at sea to sample their diet during these periods. Diet sampling of birds near to and away from fishing vessels in August - October could also help to assess the non-waste component of the diet during chick-rearing which was probably underestimated in the present study. Satellite tracking could also be carried out during other parts of the breeding cycle, for example during incubation when longer foraging trips would be expected and the level of interaction with the WCSI hoki fishery may differ.

A study of the behaviour of Westland petrels attending fishing vessels is an obvious next step for Westland petrel research. Such a study should include; observations of the number of Westland petrels attending vessels, their success in scavenging waste compared to other species, and discarding experiments to provide an indication of the quantity of waste consumed. This could be achieved by subsampling the actual waste discharged by vessels, and observing the fate of this waste once thrown overboard. The quantity of waste consumed could then be extrapolated into the proportion of energy requirements it provides for the population, providing another means of assessing the level of use of fisheries waste. Ideally, such a study would be carried out from a representative sample of fishing vessels to avoid the lack of comparability with actual fishing operations experienced by discarding studies performed from research vessels (eg Garthe & Hüppop 1994).

Conclusion

This study found that fisheries waste, particularly waste from the WCSI hoki fishery, forms a large part of the Westland petrel diet during their chick rearing period. However, extensive use of a resource does not necessarily imply dependence on that resource, and several features of the Westland petrel's breeding biology and foraging ecology suggest that Westland petrels could compensate for a reduction in waste from the hoki fishery by switching to other sources of waste and increasing their consumption of natural prey. Nevertheless, much remains unanswered about the role that fisheries waste plays. In particular, quantifying the waste available to seabirds, and the success of Westland petrels in acquiring that waste in the face of competition from other species, is needed in order to better predict the effect of a reduction in fisheries waste on Westland petrel population levels.

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